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NATIONAL ACADEMY OF SCIENCES

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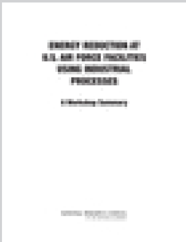

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A Workshop Summary

Gregory Eyring, Rapporteur

Committee on Energy Reduction at U.S. Air Force Facilities Using Industrial Processes: A Workshop

Air Force Studies Board

Division on Engineering and Physical Sciences

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Preface

The Air Force recognizes that energy is a strategic issue for the United States. To assist the Air Force in addressing this issue, the Air Force Studies Board (AFSB) of the National Research Council (NRC) drafted terms of reference (TOR) in April 2012 for a short workshop to bring together Department of Defense stakeholders and representatives of industry in order to highlight current approaches to industrial process energy with a goal of highlighting potential ways to reduce Air Force industrial process energy consumption.[1] The Deputy Assistant Secretary of the Air Force for Energy, Kevin Geiss, approved the TOR in April 2012 and the NRC approved the TOR in July 2012. The NRC then established the Committee on Energy Reduction at U.S. Air Force Facilities Using Industrial Processes: A Workshop to conduct a workshop, and the 3-day workshop was held on November 5-7, 2012.

The committee appreciates the support of Dr. Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy, who articulated a clear set of objectives for the workshop, and that of his staff. In addition, the committee thanks the many expert speakers and guests who contributed immensely to this undertaking. Finally, the committee's role was limited to planning the workshop. This workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop.

Kenneth E. Eickmann, *Chair*
Committee on Energy Reduction at U.S. Air Force Facilities Using Industrial Processes: A Workshop

[1]Since 2006 the AFSB has produced several reports related to Air Force energy consumption, including the following, published by the National Academies Press, Washington, D.C.: *A Review of United States Air Force and Department of Defense Aerospace Propulsion Needs* (2006); *Improving the Efficiency of Engines for Large Nonfighter Aircraft* (2007); and *Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs* (2011). All are available at www.nap.edu.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Daniel E. Hastings, Massachusetts Institute of Technology,
Gwen P. Holdmann, Alaska Center for Energy and Power,
Mark J. Lewis, IDA Science and Technology Policy Institute,
Lawrence T. Papay, PQR, LLC,
James B. Porter, Jr., Independent Consultant,
Maxine L. Savitz, Honeywell, Inc. (retired), and
Rebecca A. Winston, Winston Strategic Management Consulting.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views presented at the workshop, nor did they see the final draft of the workshop summary before its release. The review of this workshop summary was overseen by Wesley L. Harris, Massachusetts Institute of Technology. Appointed by the NRC, he was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the author and the institution.

Contents

Acronyms and Abbreviations

AFB	Air Force Base
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AFSC	Air Force Sustainment Center
ALC	Air Logistics Complex
AMC	Army Materiel Command
AMO	Advanced Manufacturing Office
AMRS	advanced meter-reading system
APTO	Advanced Power Technology Office
Btu	British thermal unit
CE	civil engineering
CII	Construction Industry Institute
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EISA	Energy Independence and Security Act of 2007
EO	Executive Order
EPACT	Energy Policy Act of 2005
ESPC	Energy Savings Performance Contract
FEMP	Federal Energy Management Program
FY	fiscal year
GM	General Motors
HVAC	heating, ventilation, air conditioning
IPE	industrial process energy
MAJCOM	Major Command

MW	megawatt
MWh	megawatt-hour
NRC	National Research Council
O&M	operations and maintenance
POM	Program Objective Memorandum
PV	photovoltaic
R&D	research and development
R&M	restoration and maintenance
UESC	Utility Energy Service Contract
USAF	U.S. Air Force
WAGES	water, air, gas, electricity, steam

Overview

The Department of Defense (DoD) is the largest consumer of energy in the federal government.[1] In turn, the U.S. Air Force is the largest consumer of energy in the DoD, with a total annual energy expenditure of around $10 billion.[2] Approximately 84 percent of Air Force energy use involves liquid fuel consumed in aviation whereas approximately 12 percent is energy (primarily electricity) used in facilities on the ground.[3] This workshop was concerned primarily with opportunities to reduce energy consumption within Air Force facilities that employ energy-intensive industrial processes—for example, assembly/disassembly, painting, metal working, and operation of radar facilities—such as those that occur in the maintenance depots and testing facilities. Air Force efforts to reduce energy consumption are driven largely by external goals and mandates derived from Congressional legislation and executive orders. To date, these goals and mandates have targeted the energy used at the building or facility level rather than in specific industrial processes.

In response to a request from the Deputy Assistant Secretary of the Air Force for Energy and the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering, the National Research Council, under the auspices of the Air Force Studies Board, formed the Committee on Energy Reduction at U.S. Air Force Facilities Using Industrial Processes: A Workshop. The terms of reference called for an ad hoc committee to plan and convene one 3-day public workshop to discuss: (1) what are the current industrial processes that are least efficient and most cost ineffective? (2) what are best practices in comparable facilities for comparable processes to achieve energy efficiency? (3) what are the potential applications for the best practices to be found in comparable facilities for comparable processes to achieve energy efficiency? (4) what are constraints and considerations that might limit applicability to Air Force facilities and processes over the next ten (10) year implementation time frame? (5) what are the costs and paybacks from implementation of the best practices? (6) what will be a

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[1]Col Douglas Wise, Chief, CE Operations and Readiness Division, HQ AFMC/A70, "AFMC Facility Energy Program," presentation to the workshop on November 5, 2012.

[2]Ibid.

[3]Ibid. The workshop focused on the approximately 12 percent of Air Force energy consumed by facilities.

proposed resulting scheme of priorities for study and implementation of the identified best practices? (7) what does a holistic representation of energy and water consumption look like within operations and maintenance?[4]

In short, the purpose of this workshop was not an in-depth analysis of energy reduction opportunities in all of the industrial processes being used at Air Force facilities, though some of the presentations touched upon opportunities in specific industrial operations (e.g., painting of vehicles at General Motors). Instead, the workshop participants reviewed and discussed the status of energy reduction initiatives already taken or planned, and discussed ways in which the Air Force could improve its approach in order to address the use of industrial process energy more effectively.

Most of the participants who spoke at the workshop indicated that the Air Force has a solid overall energy strategy, and that the representatives from the Air Force maintenance and test depots who attended the workshop have a nuanced and well thought out understanding of: (1) energy usage in general; (2) process energy, in particular; and (3) opportunities for addressing associated challenges without impact to the Air Force mission. It was the opinion of many in the workshop that with the right vision from leadership and access to resources, the facility managers the participants heard from are well positioned to implement improvements. The discussion focused on opportunities in seven areas: (1) management and leadership; (2) budgets and funding; (3) information resources; (4) metrics; (5) culture change; (6) personnel and training; and (7) investment opportunities.

MANAGEMENT AND LEADERSHIP

To most participants who spoke at the workshop, it appeared that the Air Force has a solid overall energy strategy, and that the representatives from bases such as Arnold Air Force Base and Tinker Air Force Base have a nuanced and well thought out understanding of energy usage in general and process energy and opportunities for addressing the associated challenges without impact to the mission. With the right vision from leadership and access to resources, the facility managers that workshop participants heard from appear to be well positioned to implement improvements.

BUDGETS AND FUNDING

No Air Force budget line is specifically devoted to energy. Several participants expressed that these diverse sources tend to lead to a fragmented, ad hoc approach to energy projects that lacks a long-term vision, is sub-optimized, and can lead to “color-of-money” constraints. Those participants generally felt that the Air Force use of Energy Savings Performance Contracts, per presidential order, is a good mechanism for

[4]Finally, it is important to note that this rapporteur-authored workshop summary does not contain consensus findings and recommendations, which are produced only by ad hoc NRC study committees.

providing funding for infrastructure and efficiency improvements in the absence of other funding sources. They accomplish the goal of reducing energy usage (intensity), although they do not result in cost savings to the Air Force over the near term and may actually result in cost increases if a contract needs to be "bought out" due to base closure or shifting priorities. Nonetheless, absent other funding sources, they appear to be a valid mechanism and worth implementing.

INFORMATION RESOURCES

Several participants noted that Air Force personnel should look for opportunities to identify which processes offer the biggest energy reduction return on investment (ROI) and to leverage what they know and how they do what they do through collaboration and networking with subject matter experts and consortia of organizations concerned with making processes better, faster, cheaper, safer, and more energy-efficient. Several participants noted that the Air Force Research Laboratory (AFRL) is well positioned to help the Air Force improve its energy usage and has published a description of its energy focus. However, it appeared to several participants that the relationship between the depots and AFRL is limited. They felt that AFRL could be tasked with helping the depots. This tasking would be consistent with a focus on next-generation technologies. Improvement of industrial processes is a fertile field for innovative engineering research.

METRICS

Several participants agreed that the Air Force would benefit if it had a coherent and transparent set of metrics that related energy use to the accomplishment of the mission—the desired metric for making a value proposition to decision makers and commanders. For industrial processes, this might be energy used per unit of product (e.g., General Motors uses MWh per vehicle). One way of accounting for surges in activity might be to normalize existing energy intensity metrics to the number of direct labor hours. Many participants felt that the Air Force should consider concentrating more effort on developing a set of metrics that permit it to improve its mission capability while lowering energy use and cost.

CULTURE CHANGE

Culture change needs to occur throughout the organization, and must be supported by the upper level of leadership. Many participants felt that the Air Force is making good progress toward metering individual facilities; however it is imperative that the information get back to the individual users of that facility who are in the best position to enact small, incremental changes. The Air Force estimates that behavior change can result in a 2 percent improvement in energy usage for buildings. However, one participant stressed that the overarching goal should be toward a culture shift at all levels of the organization—culture being defined as behaviors that individuals engage in even when no one is looking.

PERSONNEL AND TRAINING

Many participants expressed that it is important that individuals at all levels of management and responsibility are aware of the importance of addressing energy security/surety and costs, and that, at times, improving efficiency and reliability can result in enhancement to the mission. Some participants suggested that having mandated energy training throughout the Air Force might be a driver toward greater understanding of the problem. For example, classes are offered by the Air Education and Training Command. Another suggestion was for process managers to have energy efficiency written into their job description and performance evaluations and receive appropriate training. A key target for improving energy awareness is the acquisition community, to get life cycle energy use to be one of the criteria on which acquisition decisions are made.

INVESTMENT OPPORTUNITIES

Several speakers noted that the civil engineering (CE) community has shown the Air Force that energy reduction projects are a good investment—typically returning $2 in savings for every $1 invested. One speaker noted that specific processes such as painting offer opportunities for improvement (as the General Motors presentation showed) but there is no budget for it. The CE community typically does not own either the industrial process or the budget. Participants noted that other processes that are good candidates for efficiencies are those that generate or transfer heat or involve rotating equipment. One participant noted several potential areas for future Air Force investment:

- Work process design and associated training and audit protocols focused on business effective energy management.
- Standardization of all common, repetitive processes such as machining, parts/equipment cleaning, painting, etc. across all sites.
- Engineering evaluation of rotating and heat exchange equipment to establish life cycle energy use and operating costs.
- Formal assessments of current operations vs. standard protocol to identify short and long-term improvement actions and projects (see Appendix E for possible areas to consider).

1

Introduction

The Department of Defense (DoD) is the largest consumer of energy in the federal government at approximately $20 billion in 2011.[1] In turn, the U.S. Air Force is the largest consumer of energy in the DoD, with a total annual energy expenditure around $10 billion.[2] As shown in Figure 1-1, about 84 percent of Air Force energy is liquid fuel consumed in aviation, and about 12 percent is energy (primarily electricity) used in facilities on the ground. However, the facilities of some Air Force commands consume a comparatively high proportion of their command's total energy. For example, in the Air Force Materiel Command (AFMC), 84 percent of energy consumption occurs in facilities (at a cost of $300 million) and only 13 percent is consumed in aviation.[3,4]

INDUSTRIAL PROCESS ENERGY

This workshop was concerned primarily with opportunities to reduce energy consumption within Air Force facilities, and particularly to reduce consumption of "process energy,"[5] whichincludes energy used in industrial and test operations, laboratories, medical facilities, and data centers. A key focus of the workshop is a subset

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[1] Col Douglas Wise, Chief, CE Operations and Readiness Division, HQ AFMC/A70, "AFMC Facility Energy Program," presentation to the workshop on November 5, 2012.

[2] Ibid.

[3] Ibid.

[4] AFMC's primary mission is supporting weapon system acquisition. This is in contrast to Air Combat Command, a separate Air Force Major Command, which devotes much more resources to aviation-related energy. SOURCES: AFMC Factsheet. Available at http://www.af.mil/information/factsheets/factsheet.asp?id=143. Accessed January 23, 2013. Air Combat Command Factsheet. Available at http://www.af.mil/information/factsheets/factsheet.asp?id=137. Accessed January 23, 2013.

[5] Air Force Instruction 90-1701 defines "process energy" as "Energy directly consumed in manufacturing, maintenance, equipment overhaul, rehabilitation or refurbishment, destruction, warehousing, and similar processes, not related to the comfort and amenities of the occupants of the facility."

of process energy termed "industrial process energy" (IPE), which includes the energy-intensive industrial processes that occur within Air Force facilities, such as the following:

- Assembly and disassembly
- Avionics testing
- Engine testing
- Composite construction
- Chemical cleaning
- Heat treating
- Painting and de-painting
- Plating
- Metalworking
- Nondestructive inspection

IPE has been defined as "energy consumed by high-intensity processes or mission-critical applications that are not the traditional creature comforts of the building (e.g., heating, cooling, lighting, and domestic hot water)"[6] as shown

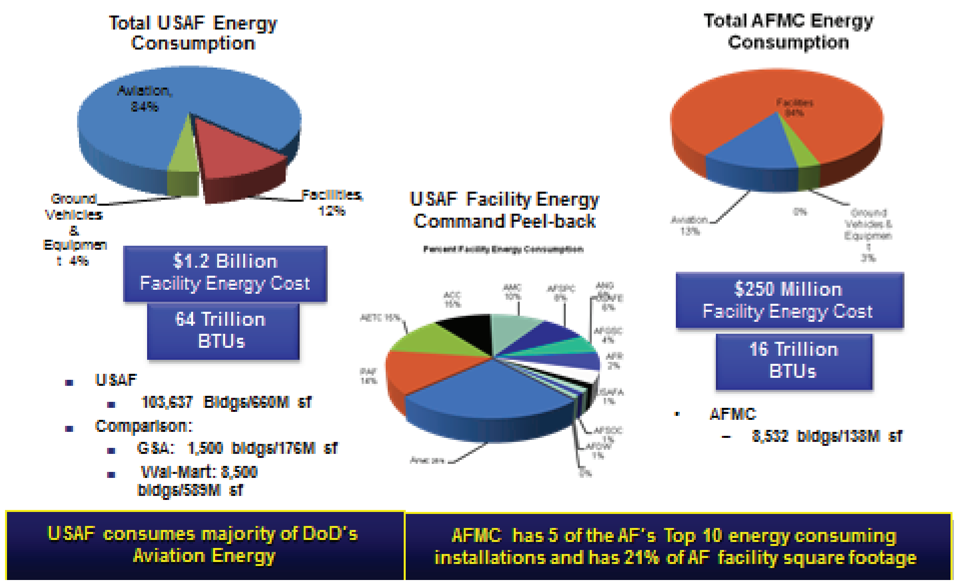

FIGURE 1-1 Breakdown of energy usage in the U.S. Air Force (USAF) and the Air Force Materiel Command (AFMC). NOTE: GSA, General Services Administration; sf, square feet. SOURCE: Col Stephen Wood, Vice Commander, 72nd Air Base Wing, presentation to the workshop, November 5, 2012, Washington, D.C.

[6] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Federal Energy Management Program.

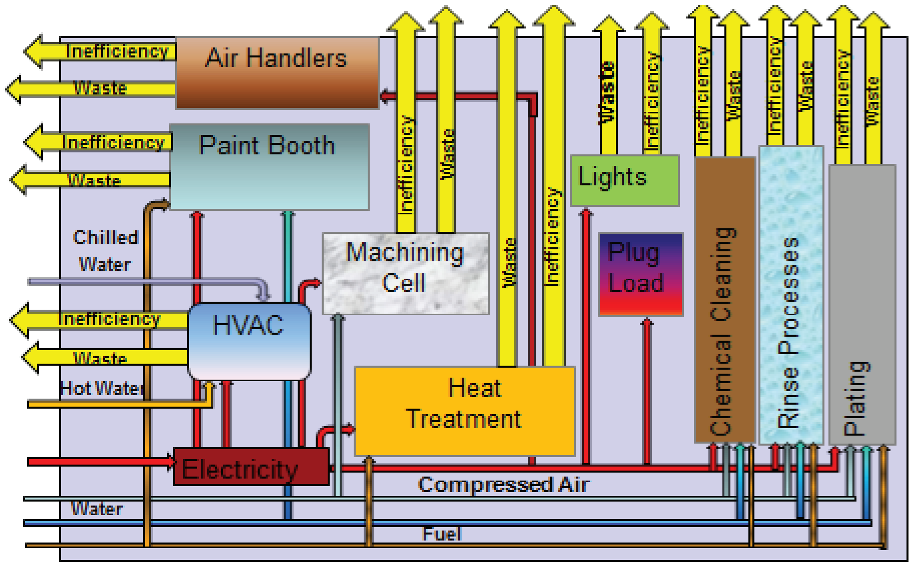

FIGURE 1-2 Examples of industrial process energy use and opportunities to improve efficiency. NOTE: HVAC, heating, ventilation, air conditioning. SOURCE: Col Douglas P. Wise, HQ AFMC A70, presentation to the workshop, November 5, 2012, Washington, D.C.

schematically in Figure 1-2. An estimated 35-50 percent of AFMC's energy consumption at its Air Logistics Complexes (ALCs) is process energy—primarily industrial process energy. Thus, although IPE is not a large fraction of overall Air Force energy use (approximately 1 percent) and has received relatively little attention, investments in IPE efficiency are expected to yield high rates of return. These reductions in energy use enhance overall Air Force energy security; the savings can be applied to enhance mission capability in other areas.

ENERGY REDUCTION GOALS AND MANDATES

The efforts of the Air Force to reduce energy consumption are driven largely by external goals and mandates derived from congressional legislation—the Energy Policy Act of 2005 (EPACT) (Public Law No. 109-58) and the Energy Independence and Security Act of 2007 (EISA) (Public Law No. 110-140)—and Executive Order 13423 (EOs), shown in Figure 1-3. To date, these goals and mandates have targeted the energy used in facilities only and not the larger amount used in aviation operations. The primary metric used in setting the goals is energy intensity, as measured in British thermal units (Btu) per square foot of facility space. The goal for facility energy is an intensity reduction of 3 percent per year from 2003 to 2015. The Air Force has made considerable progress toward its goals, having invested hundreds of millions of dollars ($274 million in FY 2011) in projects that have reduced facility energy intensity by 16 percent since the base year, 2003.[7] However, as shown in Figure 1-4, AFMC efforts are expected to fall short of the goal of a 30 percent reduction by 2015. Unless changes are made in the way that AFMC operates, targets, and funds energy-efficiency projects, the gap between goals and performance in 2015 is expected to be approximately 14 percentage points. Each additional percent of energy-intensity reduction is estimated to require an investment of $100 million. The AFMC is looking at reducing its use of industrial process energy as a way to help reach its facility energy-reduction goals.

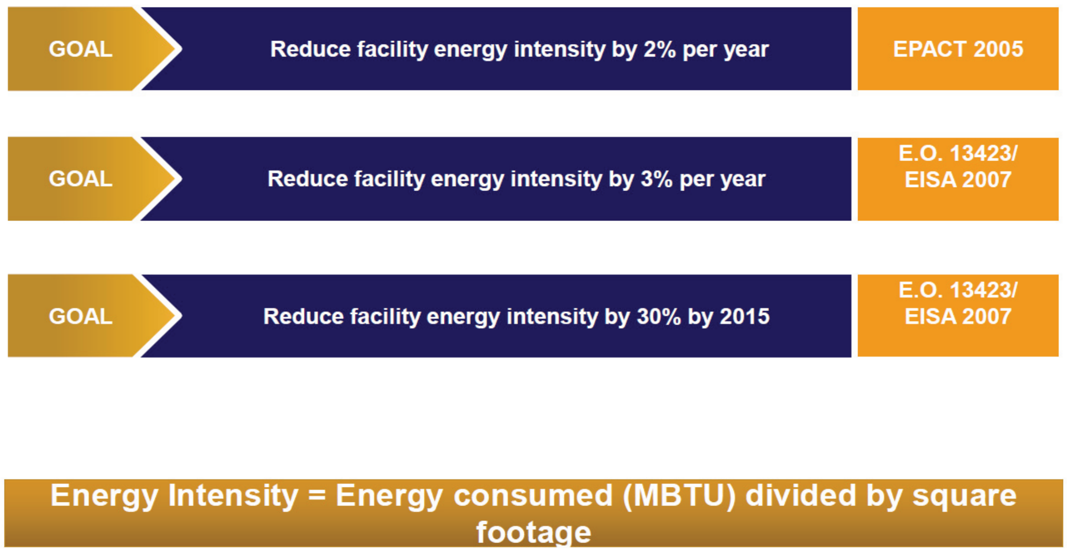

FIGURE 1-3 Mandates and goals for reducing energy intensity in U.S. Air Force facilities. NOTE: EPACT, Energy Policy Act; E.O., Executive Order; EISA, Energy Independence and Security Act. SOURCE: Kevin Geiss, Deputy Assistant Secretary for Energy, U.S. Air Force, presentation to the workshop, November 5, 2012, Washington, D.C.

[7]Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy, “National Academies Workshop: Energy Reduction at Air Force Facilities Using Industrial Processes,” presentation to the workshop on November 5, 2012.

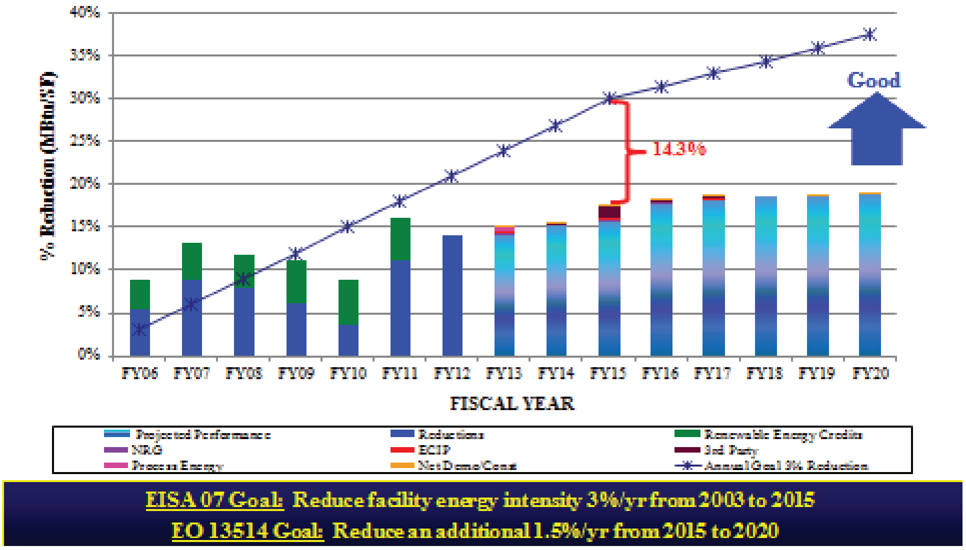

FIGURE 1-4 The gap between mandated reduction in energy intensity at Air Force Materiel Command (AFMC) facilities and actual performance is expected to increase. NOTE: NRG, Energy Conservation Initiative; ECIP, Energy Conservation Investment Program; EISA, Energy Independence and Security Act; EO, Executive Order; SOURCE: Col Douglas Wise, HQ AFMC A70, presentation to the workshop, November 5, 2012, Washington, D.C.

WATER CONSUMPTION GOALS AND MANDATES

In addition to reducing energy intensity at Air Force facilities, another area that the Air Force is targeting for efficiency is fresh-water use. In the United States, water is relatively cheap compared to electricity, but at facilities located on islands or forward operating bases, water must be brought in at great expense. Furthermore, in the next 10 to 20 years, access to potable water is expected to increasingly become an issue. Executive Order 13514 has set a goal of reducing water use by certain federal agencies by 2 percent per year from 2007 to 2020.[8] The Air Force is relatively comfortable with its progress in meeting this goal at the moment, but it recognizes that energy use and water use are often interconnected, and it is interested in developing an integrated plan for meeting its energy- and water-reduction goals.

[8]For additional information on Executive Order 13514, *Federal Leadership In Environmental, Energy,And Economic Performance*, see http://www.whitehouse.gov/assets/documents/2009fedleader_eo_rel.pdf. Accessed January 11, 2013.

WORKSHOP TERMS OF REFERENCE

In April, 2012, the Air Force Deputy Assistant Secretary for Energy requested that the National Research Council (NRC) conduct a workshop titled "Energy Reduction at Air Force Facilities Using Industrial Processes," and produce a summary report. The terms of reference (TOR) for this workshop are shown in Box 1-1.

BOX 1-1

Terms of Reference

An ad hoc committee will plan and convene one 3-day public workshop to discuss: (1) what are the current industrial processes that are least efficient and most cost ineffective? (2) what are best practices in comparable facilities for comparable processes to achieve energy efficiency? (3) what are the potential applications for the best practices to be found in comparable facilities for comparable processes to achieve energy efficiency? (4) what are constraints and considerations that might limit applicability to Air Force facilities and processes over the next ten (10) year implementation time frame? (5) what are the costs and paybacks from implementation of the best practices? (6) what will be a proposed resulting scheme of priorities for study and implementation of the identified best practices? (7) what does a holistic representation of energy and water consumption look like within operations and maintenance?

The committee will develop the agenda for the workshop, select and invite speakers and discussants, and moderate the discussions.

The topics at the workshop will also consider effective strategies and business approaches to foster culture change and select technology portfolios that could reduce infrastructure energy and water consumption and increase resilience at military installations while assuring energy for mission critical capabilities across the Department of Defense. Special attention will be given to installations that have antiquated facilities, massive industrial processes, and demolition/consolidation opportunities. The workshop will use a mix of individual presentations and question-and-answer sessions to develop an understanding of the relevant issues. Key stakeholders would be identified and invited to participate. One individually authored Workshop Summary document will be prepared by a designated rapporteur.[1]

[1] Finally, it is important to note that this rapporteur-authored workshop summary does not contain consensus findings and recommendations, which are produced only by ad hoc NRC study committees.

WORKSHOP STRUCTURE, SCOPE, AND APPROACH

This 3-day workshop, which took place November 5-7, 2012, in Washington, D.C., consisted of a series of presentations to workshop participants by invited speakers (the workshop agenda is provided in Appendix B), with each presentation followed by general discussion. Broadly, the first day was devoted to presentations on energy-reduction efforts by the Air Force and the other services, the second day to presentations on commercial industry initiatives, and the third day to discussion among all participants.

It quickly became apparent that neither the expertise represented nor the time available would permit an in-depth analysis of energy-reduction opportunities in all of the industrial processes being used at Air Force facilities, as outlined in the first paragraph of the TOR (see Box 1-1). Although some of the presentations—especially those by industry representatives—touched on energy-reduction opportunities in specific industrial operations (e.g., the painting of vehicles at General Motors), most dealt with energy-reduction initiatives, programs, information resources available, and strategies for implementing culture change with respect to how energy is used in the Air Force.

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Presentations and Comments

The workshop participants heard a series of presentations on energy-conservation efforts within the military services and in private-sector companies representing the aircraft, chemical, automobile, and armaments industries (see the workshop agenda, Appendix B). Abstracts of these presentations are provided in Appendix D. A brief summary of the main points of the presentations and the ensuing discussion is given next, in chronological order of presentation.

MONDAY, NOVEMBER 5, 2012

Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy

Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy, presented the primary motivation for reducing energy consumption—to support the Air Force mission. He discussed the Air Force's three-fold strategy: (1) reduce demand, (2) increase supply, and (3) change the culture, and noted progress toward the goals shown in Figure 1-3 in Chapter 1. A key need is to install meters to provide data on electricity use with finer precision so that they can determine what specific processes and equipment are using the energy and where the major opportunities are. Each facility's energy use is unique and dynamic as workloads change. Furthermore, Geiss noted, culture change takes time. Personnel need to be encouraged to be innovative and must receive appropriate training to be able participate effectively in efforts aimed at reducing energy consumption. Without more data on energy use, "You don't know what you don't know." The question was raised as to whether there is any evidence that installation of smart meters actually results in energy savings. The biggest gains may require automated energy management control systems—that is, going beyond just providing data for energy analysis.

Joseph Sikes, Director of Facilities Energy Privatization, Office of the Deputy Under Secretary of Defense for Installations and Environment

Joseph Sikes, Director of Facilities Energy Privatization, Office of the Deputy Under Secretary of Defense for Installations and Environment, emphasized the main objective of Department of Defense (DoD) energy projects—to do the mission better. Recent initiatives have included expanding the use of renewables, installing microgrids, and technology development. At the end of the year, all of the military services will report data on energy use. This information will be put into an online database to increase visibility. An annual energy management report is expected to be released in March 2013, in which all bases will be listed by energy-intensity and energy-reduction targets. Sikes noted that facilities use 20 to 25 percent of DoD energy. The energy-intensity metric (British thermal units per square foot) is far from ideal, but “one we are stuck with.” Unless it is adjusted for changes in external factors, it can give the wrong answer. For instance, when soldiers return from deployments overseas, energy use on U.S. bases goes up, even if the buildings have become more efficient. In that case, British thermal units per person would be a better metric. Also, consolidation of data centers or demolition of unneeded buildings, which can be desirable from an efficiency point of view, reduces the overall square footage and therefore increases the energy-intensity metric. Most of the direct spending on energy within DoD is on expanding renewable-energy projects. In principle, renewables provide a distributed source of energy at a base, and so a base is more secure in a crisis if it is set up so that it can be switched from the grid to a local microgrid on the base. Unfortunately, we are not there yet, and the renewable projects do not pay back the investment unless the bases are on islands (e.g., Kwajalein, Shemya, Diego Garcia) or are otherwise difficult to supply (e.g., Djibouti).

Sikes related that considerable gains in reducing energy use can be made just by gridding the generators on a base so that energy output can be tuned to the electricity demand. The Navy has done considerable work on optimal gridding of shipboard generators. Another opportunity involves peak shaving and demand-side management, in which bases can save a lot of money by working with local utilities. He also noted that there is a memorandum of understanding among major federal agencies (including the Department of Energy [DOE], the DoD, and the Department of Homeland Security) to promote emergency-management cooperation with local authorities, and that military bases are working more closely with government and private entities outside the base. If closer cooperation could be established between the DoD, local energy utilities, and federal regulators of local utilities, then some of these costs could be reduced at many installations. The local utilities are not depending on the fees from the bases, but they have to keep a higher capacity level by law because the solar capacity is not counted.

One participant noted that the metric for renewable energy—the quantity procured or produced divided by total energy—does not actually address either energy reduction or energy security. It is important to review this metric so that it does not cause unintended consequences. Another observer noted that although the acquisition of new military systems and equipment provides a unique opportunity to consider life-cycle energy efficiency, there is currently no directive to the acquisition community to enable serious investment in energy reduction. Stated differently, this not just as an investment in energy reduction, but as part of the life cycle cost of purchasing and operating the equipment, rather than just the capital cost for it. More efficient equipment is often more costly upfront, but less expensive when considering the full lifecycle costs. Energy considerations need to be threaded throughout the business analysis in acquisition decisions, and they need to be codified in guidance that carries weight.

Paul Bollinger, Director, Boeing Energy

According to the presentation by Paul Bollinger, Director, Boeing Energy, Boeing takes a life-cycle approach to reducing its environmental footprint—including that related to energy consumption, greenhouse gases, water consumption, hazardous waste, and solid waste. It has an integrated management system for measuring and reporting on progress, with a roll-up that can focus on sites, regions, or enterprise-wide results. “It comes down to culture,” he said. More than 6,000 employee-involvement teams meet once per week. Boeing received the 2012 Environmental Protection Agency Energy Star Partner of the Year award. Its chief executive officer is publicly committed to conserving energy, and its energy consumption has decreased since the base year 2007 despite increased production of aircraft.

The discussion after the presentation explored Boeing’s motivations for reducing energy. Boeing’s 787 aircraft is sold in part for its fuel efficiency. By extension, customers are also looking at the production efficiency. Commercial airlines focus on energy efficiency, which is tracked for each pilot and aircraft tail number. Significant savings have been achieved simply by adjusting the center of mass of the aircraft for optimum efficiency. Bollinger noted that the military does not have the same financial motivation as that of a commercial enterprise. He observed that support for energy conservation comes and goes in the various military services and that officers need to be held accountable for making progress on the energy front. Big fuel savings are possible when equipment is replaced—for example, when the Joint Surveillance Target Attack Radar System program transitioned to the more efficient Boeing 737 aircraft.

Col Douglas Wise, Chief, Civil Engineering Operations and Readiness Division, HQ AFMC/A70

Five of the top 10 energy-consuming installations in the Air Force are within AFMC, including the three air logistics complexes (ALCs): Oklahoma City ALC, Oklahoma (#1), Ogden ALC, Utah (#3), and Warner Robins (ALC), Georgia (#7). Col Douglas Wise, Chief, Civil Engineering Operations and Readiness Division, Headquarters Air Force Materiel Command (AFMC), estimated that for AFMC to reach its energy-reduction goals in FY 2015 would require investing the entire operations and maintenance (O&M) budget of the Air Force. Installations are not able to keep the money that they save with from energy-reduction investments, and so they have less incentive to make these investments. An ongoing point of friction is that of relating energy savings to the mission—for example, how does a 1 percent energy saving affect the mission?

FY 2010 saw the first standardized reporting of energy intensity, in the form of standard spreadsheets that could be shared with all installations. Water use is not currently metered, but the goal is to do so in the 2015-2016 time frame. Several potential sources of money, or "colors of money," are available to fund energy projects. These include O&M ("3400" funds); research, development, testing, and evaluation ("3600" funds); and capital investment funds. These funding sources are not fungible—that is, one cannot use 3400 funds for projects at test facilities. In FY 2009, focus funds (approximately $200 million per year) were set aside in the O&M budget for energy-related projects, and the Major Commands (MAJCOMs) were asked to submit project proposals with estimated returns on investment. In addition, Energy Savings Performance Contracts (ESPCs), which fall under Executive Order,[1] and Utility Energy Service Contracts (UESCs), in which third-party companies come in and do projects to improve a facility for a fixed fee, are options available to the Air Force. In that case, the company owns and maintains the infrastructure and captures any long-term profits. Col Wise estimated that the private sector (e.g., Wal-Mart) invests about 3 to 4 percent of its budget in renewing its infrastructure, whereas the DoD/Air Force invests about 1 percent.[2]

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[1]For additional information, see *Presidential Memorandum -- Implementation of Energy Savings Projects and Performance-Based Contracting for energy savings*. December 2, 2011. Available at http://www.whitehouse.gov/the-press-office/2011/12/02/presidential-memorandum-implementation-energy-savings-projects-and-perfo. Last accessed on December 27, 2012.

[2]The Air Force has historically invested at 2 percent (or less) of plant replacement value on operations and maintenance (O&M) and recapitalization. O&M is the day-to-day maintenance of a facility while recapitalization is the replacement of building subsystems, to include roofs, HVAC, control systems, paving, fire protection apparatus, among other items. Recapitalization may vary as a facility ages; that is, you will likely spend more on recapitalization as subsystems fail. There are differing opinions on a good rule of thumb for O&M and recapitalization. One estimate cites 4 percent (2 percent for O&M and 2 percent for recapitalization). For additional information, see For additional information, see http://www.tradelineinc.com/reports/E81F7036-BECE-11D4-95B9005004022792. Other estimates recommend 29 percent for O&M and 4 percent for recapitalization. For additional information, see http://www.tradelineinc.com/reports/59A81BA1-DB23-11D4-95BA005004022792/0/0/. Either way, the

Civil engineering (CE) personnel manage the installation of meters and other building-related projects, but logistics personnel have responsibility for the industrial processes that go on inside the buildings. The ALCs lack a funding source for conservation programs. The CE side can help, but it cannot drive the process. The CE and sustainment communities need to work together. The AFMC is undergoing a management change in which 12 sustainment centers are being reorganized into 5, with each center overseeing multiple installations. This reorganization provides an opportunity to increase the visibility of process energy efficiency. The ensuing discussion raised several points. One participant noted that it is sometimes difficult to cleanly define “process energy.” In paint hangars, for example, the heating, ventilation, and air conditioning (HVAC) system serves the dual purpose of maintaining a comfortable temperature as well as providing heat for the painting process. This can cause problems when investment is required and funding sources have definite colors. Fifteen years ago, pollution prevention was integrated into the depots. The personnel already exist and could be repurposed to focus on energy reduction—it is not a personnel issue. Indeed, pollution prevention money has been used for energy projects at Tinker AFB.

Col Stephen Wood, Vice Commander, 72nd Air Base Wing, Tinker Air Force Base

Col Stephen Wood, Vice Commander of the 72nd Air Base Wing, Tinker AFB, discussed efforts to reduce process energy at the Air Force Sustainment Center (AFSC), one of the reorganized sustainment centers in AFMC, based at Tinker AFB. He noted that the mandated energy meters have been purchased and that installation at the building level should be completed by the spring of 2013. Submetering, or metering of individual processes inside buildings, at the industrial process level has not yet been accomplished, but it will be needed in order to provide data to process owners. Lt Gen Bruce Litchfield, commander of the AFSC, has set a goal of 5 percent reduction in energy consumption per year, which goes beyond the federal goals. AFSC has identified the major inefficiencies in its industrial processes, and is initiating partnerships with local government, industry, and academia to address them. Challenges include low utility rates across the complexes and changing processes that place limits on the required investment-payback times for energy-reduction investments. The discussion following this presentation focused on opportunities to work with local utilities to reduce electricity costs. Utilities have an incentive to reduce peak loads through demand-side management programs and interruptible power deals that lead to lower rates to customers.

Air Force is below recognized standards. Also, the figures cited by Col Wise include only real property assets, not equipment items, such as dipping tanks, spray booth equipment, among other items. SOURCE: Col Douglas Wise, Chief, CE Operations and Readiness Division, HQ AFMC/A70. Personal communication to Carter Ford on December 19, 2012.

Kirk Rutland, Technical Director, Test Sustainment Division, Arnold Engineering and Development Complex

Kirk Rutland, Technical Director of the Test Sustainment Division, Arnold Engineering and Development Complex, explained how Arnold creates flight-test conditions on the ground; the controlled conditions provide better test data, and ground testing is more cost-effective and efficient than air testing. A huge amount of energy is required to "create the conditions." The test workload constitutes approximately 93 percent of the power demand, which is 18 megawatts (MW) on average, but can surge to a peak of 400 MW, equivalent to about one-third of the power average demand of Nashville, Tennessee. Customers are generally the acquisition community, who need the test data to help them make decisions. Much of the infrastructure at Arnold is from the 1940s and 1950s, but it still works, and even though it is not the most efficient, its replacement is a low priority. Fighting obsolescence of infrastructure is a much bigger concern than energy efficiency, although there are opportunities for efficiency improvements when infrastructure is replaced.

The metric of performance at Arnold is "more data in less time," not energy efficiency, Rutland explained. If a test campaign can be shortened by several days, much more money is saved than could be saved by energy efficiency. Process energy use is not metered. Some energy use at Arnold is excluded from the Air Force energy bill, so the question is asked—what is the incentive? Energy-efficiency investment costs cannot be passed on to the customer, so the question is, where to go for money for reducing process energy use? During the discussion, the question was raised as to whether the ideal efficiency of test processes at Arnold is known. The answer was that no studies have been done. Energy use per test data point has not been tracked. A related point is that responsibility for managing energy use at Arnold tends to be placed on civil engineering personnel, who do not have the expertise to address processes in which the bulk of energy is used.

Cameron Stanley, Support Contractor, Advanced Power Technology Office, Air Force Research Laboratory

Cameron Stanley, Support Contractor, Advanced Power Technology Office (APTO), Air Force Research Laboratory (AFRL), indicated that APTO is supporting energy-related projects in five bucket areas: hydrogen, renewable energy integration, waste to energy, advanced energy technologies, and energy storage. There are three crosscutting focus areas: operational energy, process energy, and energy security. Congress recently added $40 million to APTO's budget to implement new cutting-edge technologies. Stanley stated that technology solutions (e.g., energy storage) must be tailored to specific environments and/or applications. To be successful, AFRL needs better requirements for Air Force energy-related projects and also good technology-transition partners. The metrics also need to be appropriate. For instance, investments in the cyber area often lead to smaller, faster processing, and this investment is desirable; however, the processors also tend to have a higher energy intensity. A point raised in the discussion is the importance of getting young, energetic students involved in these energy technology projects, whether at the Air Force Academy or through the Air Force Institute of Technology (AFIT) at Wright-Patterson AFB, Ohio.

Concluding Discussion

The November 5 session ended with a discussion of the presentations and discussions that the workshop participants had heard. Participants noted that the Air Force had demonstrated progress on energy issues, at least at the MAJCOM level, although less so at higher levels. The Air Force Council has responsibility for achieving efficiency targets and subpanels of the Council are concerned with energy, but some workshop participants argued that a continuing effort will be needed to ensure that the gains are sustainable. Wal-Mart has the slogan “Save Energy, Live Better”; the Air Force needs a slogan such as “Save Energy, Fight Better.” Partnering among the Air Force, government, and industry was viewed by many workshop participants as an important way forward. An example of a potential source of useful information for the Air Force is the Construction Industry Institute (CII) at the University of Texas that brings together key private companies and government agencies. Funding issues are key to progress in this area. Many participants stated that proper incentives for improving energy efficiency are needed. Trade-offs between reducing energy use and meeting readiness objectives need to be explored. The proper approach is one of balance, and identifying when both efficiency and conservation strategies could impact the mission versus just require a change in culture (as conservation frequently does). It was also noted that having the right sensors and meters to measure energy use is important in order to effect change. Proper metrics are also needed. For example, energy intensity measured in British thermal unit per square foot, while a good metric for office space and living quarters, is not a very good metric for process energy use. It was argued that the Air Force has been focused on the low-hanging fruit in facility energy use, whereas technology improvements are needed but not funded. How can a process that has twice the throughput at half the cost be implemented?

TUESDAY, NOVEMBER 6, 2012

Robert Gemmer, Technology Manager, Advanced Manufacturing Office, Office of Energy Efficiency and Renewable Energy, Department of Energy

Robert Gemmer, Technology Manager from the Advanced Manufacturing Office (AMO) in DOE’s Office of Energy Efficiency and Renewable Energy (EERE), was invited to give an unscheduled presentation on AMO’s outreach to industry in its effort to improve the energy efficiency of industrial processes. There are now industrial assessment centers[3] at 26 land-grant universities aimed at educating students and identifying ways to assess and improve industrial processes such as the following: (1) process heating (which accounts for one-third of all industrial energy use), (2) boilers and steam delivery, (3) compressed air, (4) air movement systems, and (5) motors. AMO has developed a suite of software tools[4] for identifying where the energy savings opportunities are. A group of 200 qualified specialists trained in the use of these tools is available for outreach. A small subset of these specialists, the "energy experts," is able to teach the use of the tools and are available to work with clients.[5] Former Secretary of Energy Samuel Bodman instituted a program in which 200 industrial facilities were checked for opportunities to reduce energy use in steam and process heating. The program identified $500 million in potential savings, of which 40 percent ($200 million) has been realized. A list of participants is available. DOE has also calculated the theoretical energy required to process materials, and has estimated the practical energy minimum for the same processes.[6] During the discussion of this presentation, several workshop participants from industry praised the Industrial Assessment Centers of AMO, noting that they had used these centers as training opportunities for their own employees.

Thomas Hicks, Deputy Assistant Secretary of the Navy for Energy

The Navy does not promote an energy/environmental agenda per se—like the Air Force, it is explicitly concerned with energy security and combat capability. Deputy Assistant Secretary of the Navy for Energy Thomas Hicks gave a high-level overview of the Navy's energy-related programs, including goals for alternative energy (e.g., waste to energy, biofuels) and renewables, power purchase agreements, and culture change. Incentives are given to commanders to be more efficient, and awareness of energy use has made facilities more efficient. The latter effort led to a 10 percent reduction in energy used in housing. The Navy has made a conscious effort to bring energy guidance as a factor into the acquisition process; Hicks cited an energy-efficient landing ship as an example. Much of the ensuing discussion focused on skepticism regarding the cost-effectiveness of investments in renewables and other energy projects. It was pointed out that it is necessary to take advantage of renewable energy credits and tax incentives to make the investments attractive for third-party power purchase agreements, and "take or pay" guarantees have to be provided so that if a base is closed or another

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[3]Additional information on Industrial Assessment Centers can be found at http://www1.eere.energy.gov/manufacturing/tech_deployment/iacs.html. Accessed November 20, 2012.

[4]Additional information on energy assessment tools can be found at http://www1.eere.energy.gov/manufacturing/tech_deployment/software_ssat.html. Accessed November 20, 2012.

[5]Additional information can be found at http://www1.eere.energy.gov/manufacturing/tech_ deployment/assessment_process.html. Accessed November 20, 2012.

[6]Additional information on DOE's Clean Energy Application Centers can be found at http://www1.eere.energy.gov/manufacturing/resources/footprints.html. Accessed November 20, 2012.

energy source is chosen, the third party will be compensated for its investment. Part of the problem is that energy security and mission capability are not monetized. Platforms may use more energy but provide more capability; the Joint Strike Fighter is an example. It is important to have energy metrics but, although they should be a factor, they should not be the only factor.

Sandrine Schultz, Energy Program Manager, Commander, Navy Installations Command

Sandrine Schultz, Energy Program Manager for the Navy Installations Command presented a developing heads-up "dashboard" tool that displays data on energy intensity from building-level meters overlaid on a geospatial map of the facility to promote awareness of energy use and to show improvements for both field personnel and managers (see Figure 2-1). The display is very intuitive, with problem buildings shown in red and satisfactory buildings in green. The data can be rolled up at various levels, from individual units in facilities to entire facilities. The module is updated on a monthly basis (for example, to account for buildups in places such as Guam), and data

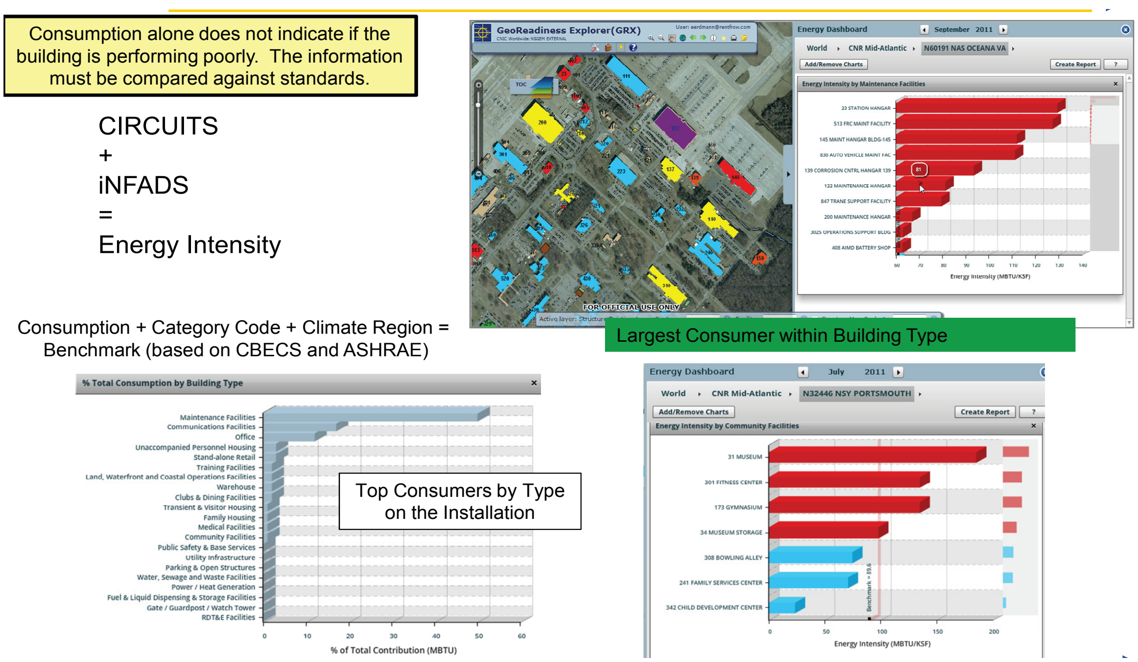

FIGURE 2-1 Example of the energy-intensity dashboard display being developed by the U.S. Navy. Metering data on the intensity of energy use is overlaid on geospatial facility maps, with colors indicating building performance. NOTE: CBECS, Commercial Buildings Energy Consumption Survey; ASHRAE, American Society of Heating, Refrigerating, and Air-Conditioning Engineers. SOURCE: Sandrine Schultz, Energy Program Manager, Commander, Navy Installations Command, presentation to the workshop, November 5, 2012, Washington, D.C.

errors are corrected immediately. The energy dashboard tool is to be made available throughout the Navy on November 17, 2012. The general response of the participants to this presentation was very favorable, and the suggestion was made that the Air Force may wish to adopt a tool like this as a way to monitor and promote its own energy-reduction efforts.

John Dwyer, Deputy Chief of Staff for Logistics, Army Materiel Command

The Army's goals and programs for energy-use reduction, development of renewables, and water conservation are similar to those of the Navy and the Air Force as discussed above, according to John Dwyer, Deputy Chief of Staff for Logistics, Army Materiel Command (AMC). There is a full-time civilian energy manager (GS 12 to GS 14) at 95 percent of Army installations. Savings identified by these managers have yielded a return on investment (ROI) in their salaries by a factor of five. There are weekly installation briefings on energy with high commander visibility. Capital investment program projects require the metering of electricity and are not approved if they are not expected to result in energy savings. The Army also uses the energy-intensity metric, but normalizes it by direct labor hours to account for changes in personnel levels.

Budgets available for funding energy-related projects in AMC are predicted to shrink in coming years. The AMC has identified its most energy-intensive processes through energy audits. It relies heavily on ESPCs with third parties to address these. Equipment used directly on the production line is paid for by Army core funding, and the infrastructure is financed by third parties. About $360 million is estimated to be needed to enable AMC to meet its energy intensity reduction goals—about two to three times its annual energy expenditure. Therefore, private sector financing through various mechanisms is viewed as critical for success. Several participants viewed with favor the normalization of the energy-intensity metric by direct labor hours, noting that further adjustments were needed to account for changes in facility square footage through consolidation, demolitions, or base closures. The question was raised as to whether funds that might materialize from the return of Army facilities in Germany to the German government could be made available to fund energy projects. The answer was that those funds would remain in Germany for use in future construction projects there.

Timothy Unruh, Program Manager, Federal Energy Management Program, Office of Energy Efficiency and Renewable Energy, Department of Energy

The Federal Energy Management Program (FEMP) provides the services, tools, and expertise to federal agencies to help them achieve their energy-use, greenhouse gas, and water-consumption reduction goals as mandated by legislation and Executive Orders. Timothy Unruh, Program Manager for FEMP, in DOE's EERE, noted that the Air Force is ahead of the rest of the federal government in meeting its goals for energy- and water-consumption reduction. FEMP is also working with the military academies to give energy-related awards to students, in categories defined by the academies.

A December 2, 2011, Presidential Memorandum[7] stated that "The Federal Government will enter into a minimum of $2 billion in performance-based contracts in Federal building energy efficiency within 24 months." FEMP coordinates these contracts, 39 of which have been awarded, with a total value of $427 million. An example is an $80.7 million ESPC signed in August 2012 at Tinker AFB that is expected to reduce energy intensity by 30 percent and save $6.4 million per year. The project decentralizes steam heating so that steam will no longer be sent long distances. These third-party projects typically take about 2 years to develop, then another 2 years to show results. It is not known how the $2 billion goal, which does not require any appropriation, matches the actual need. One comment following this presentation was that there needs to be an understanding of what it is that one wants to meter and of what meters or sensors are most appropriate to the task. A process expert should select the right meter for a particular process. In some cases, a 15-minute meter may be useless and a 30-second meter may be right. A second comment suggested an alternative metric for evaluating project success: dollars invested per British thermal unit saved. A dollar invested should yield a 6,000-8,000 Btu reduction.

Al Hildreth, Company Energy Manager, General Motors North America

General Motors (GM) has an annual energy budget of approximately $1 billion and a robust business process to manage it, according to Al Hildreth, Company Energy Manager for General Motors North America. Goals have been set by top management to reduce energy, greenhouse gases, and water use, and GM participates in the Energy Star program. All plants are ISO 50001-certified. GM uses the metric megawatt-hours (MWh) per vehicle to measure its energy intensity; in North America it currently requires 2.59 MWh to produce a vehicle, equivalent to the electricity used by one household in a year. GM uses a proprietary energy-management dashboard display to track energy intensity that half of its plants currently feed into.

GM estimates that 60 percent of its energy consumption is due to processes and has conducted audits to identify opportunities for reduction. The largest electricity user is the paint shop. Hildreth discussed a series of steps that were taken to improve energy efficiency in painting operations, the most significant of which was increasing the fraction of recirculated air to outside air. Annual energy savings from taking these steps amounted to nearly $3 million. Most participants were favorably impressed by GM's program and its energy-intensity metric, and thought that the Air Force's efforts to

[7] For additional information, see "Presidential Memorandum -- Implementation of Energy Savings Projects and Performance-Based Contracting for energy savings." December 2, 2011. Available at http://www.whitehouse.gov/the-press-office/2011/12/02/presidential-memorandum-implementation-energy-savings-projects-and-perfo. Last accessed on December 27, 2012.

reduce industrial process energy would benefit from a closer collaboration with companies such as GM.

James B. Porter, Jr., Independent Consultant

As indicated by James B. Porter, Jr., retired vice president for engineering and operations at DuPont, DuPont consumes 129 trillion Btu of energy per year, compared with the Air Force's 65 trillion Btu. DuPont's business goal is "sustainable growth" that entails increasing shareholder and societal value while decreasing the footprint of operations. In 1999, DuPont announced the goal of holding energy use at or below the 1990 baseline, with additional goals for greenhouse gases and renewable energy use. In fact, DuPont has achieved a 6 percent reduction in energy consumption since 1990, despite the 40 percent increase in production. The commitment of senior leadership to sustainable growth is the key to DuPont's success; this commitment percolates down through the enterprise. A single site manager at each plant is responsible for all aspects of operations, including meeting energy-savings targets. Energy-use data are aggregated at the site level. The metric is energy dollars spent last year divided by energy dollars spent this year. It is important to keep the value proposition in front of managers and stockholders, Porter noted. DuPont estimates that it has gotten a 60 percent internal rate of return from its investment in energy projects.

DuPont has many subject-matter experts in energy-related issues. They are deployed by means of a leveraged model to maximize effectiveness and efficiency. Peer-to-peer forums of energy champions have been key enablers. Technology is also being used to promote energy savings, with a website that disseminates best practices, downloadable energy engineering assessment tools, and virtual workshops that enable energy training without the necessity of travel. Peer recognition for meeting energy goals is important, perhaps more so than recognition by management. The DuPont culture is that all energy-management projects are good business projects. The notion of "sustainable energy management" seemed to resonate with the Air Force participants in the workshop, as well as the emphasis on the commitment of top leadership. In response to a question, Porter noted that the energy-efficiency culture promoted by DuPont has also spilled over into the energy choices that their employees make in their personal lives.

Roger Weir, Energy Manager, ATK Aerospace Systems

As noted by Roger Weir, Energy Manager for ATK Aerospace Systems, ATK is the world's top producer of solid rocket propulsion systems and military ammunition. Its operations are widely dispersed, with some 24 offices and operating locations in 23 states. Starting in 2009, each location was required to develop an energy plan, but communication among sites and sharing of best practices have proved challenging.

Annual energy spending is $70 million, and 7.3 trillion Btu are consumed. No funds are specifically allocated for energy projects, which must compete for funding with other projects. ATK has a dashboard display system for tracking water, air, gas, electricity, and steam (WAGES) consumption on a monthly basis and comparing it to budget targets, primarily for primary process building owners. Annual pay increases are tied to cost reduction in these areas. Weir cited several projects involving improvements to processes that had significant energy savings, although the motivation for undertaking them was to increase throughput:

- Replacing an electric furnace with a natural gas furnace.
- Replacing a gas-fired continuous line anneal furnace with a cellular electric furnace,
- Replacing an old anneal furnace with a new one that has improved insulation,
- Modernizing steam boiler controls, and
- Installing remote maintenance of an HVAC system with an automatic trouble notification system.

ATK believes that the future sustainable grid will involve much more distributed electricity generation, with energy storage technologies becoming more prevalent. Weir described a 3-year joint project between DOE and ATK to explore several of these technologies and to gather data on their performance.

Kenneth Walters, Chief, Measurement and Analysis Division, Air Force Civil Engineer Center–Energy, Air Force Materiel Command

Kenneth Walters, Chief of the Measurement and Analysis Division of the AFMC's Air Force Civil Engineer Center—Energy, was invited to give an overview of progress in the metering of electricity use in Air Force facilities. The Energy Policy Act of 2005 mandates that federal agencies put meters on all facilities where it is cost-effective. To judge cost-effectiveness, the Air Force uses an algorithm based on the estimated amount of electricity used in a building and the cost of the electricity, and it assumes that at least 2 percent of electricity costs would be saved just from the awareness that an installed meter would provide. Fully burdened, the cost of installing a meter is about $10,000. If savings are calculated to be a few thousand dollars per year, this is judged to be cost-effective. Some 74 percent of the mandated electricity meters have been installed at Air Force facilities, at a cost of $100 million. The remainder are expected to be installed in the next few months. Military construction specifications require meters on all new buildings.

The Air Force has already contracted out the development of an advanced meter-reading system (AMRS) that will provide a dashboard display of electricity use enterprise-wide, similar to the system described above being developed by the Navy. It is expected to be deployed over the next 2 years. Submetering of specific processes has not yet been addressed, but it is not precluded. One problem is that the meters are of different types and they talk to different proprietary systems, so in some cases it is necessary to pull data from alternative sources.

Col Steven Wood, Vice Commander, 72nd Air Base Wing, Tinker Air Force Base

Col Steven Wood was asked to comment on relevant activity at Tinker AFB, which is a joint Air Force and Navy base with good cooperation between the two. The Navy pays for its electricity based on its usage. From the perspective of the Air Force,, electricity use at Tinker AFB is reported as the fenceline electricity minus amounts attributed to other customers and tenants. In 2009, Tinker AFB took over an old GM plant that was only lightly used, and so the energy-intensity metric dropped (due to the increase in the denominator square footage). Tinker AFB has purchased meters to monitor electricity, gas, and water usage, although they are not all installed. Current energy projects do not yet address industrial process energy, but Tinker AFB is ramping up a team to focus on process energy, as are Hill AFB, Utah, and Robins AFB, Georgia.

WEDNESDAY, NOVEMBER 7, 2012

Col Gregory Ottoman, Chief, Environment and Energy Division, Office of the Deputy Chief of Staff for Logistics, Installations, and Mission Support

Col Gregory Ottoman, Chief of the Environment and Energy Division, Office of the Deputy Chief of Staff for Logistics, Installations, and Mission Support, noted that the progress of the Air Force in reducing facility energy intensity (16.8 percent since 2003) leads the other services. The Air Force has three reasons to invest in energy projects: (1) It must try to meet congressional and presidential mandates; (2) the savings in utility costs are considerable, with about $2 dollars saved for every dollar invested; and (3) reducing energy use contributes to national security (although there is no price tag on this benefit). It all boils down to funding, Ottoman said, and finding the dollars to invest will get harder in the future. Restoration and maintenance (R&M) funds for retrofitting facilities that are currently being set aside for energy projects will no longer be set aside in FY 2016, and so energy projects will have to compete with all other projects. These funds can’t be used for improving industrial processes or for laboratories. There are no excess dollars in the infrastructure budget; about $1 billion is available, but the backlog is around $33 billion.

Leadership needs to decide to dedicate funding to energy projects. There is an oversight and resourcing council chaired by Terry Yonkers, Assistant Secretary of the Air Force for Installations, Environment and Logistics, that has energy as part of its purview. The focus of federal mandates and EOs on the relatively small fraction of Air Force energy consumed in facilities rather than the much larger fraction used in aviation appears to be skewed, but this is changing. One stated goal was to reduce aviation fuel use by 10 percent from 2006, but this goal has not been met due to the wars in Iraq and Afghanistan. There are expected to be new initiatives on reducing fuel use in aviation in this Program Objective Memorandum (POM) cycle.

Ottoman argued that the metrics for measuring energy intensity may be appropriate for office buildings but are not appropriate for addressing industrial process energy. Also, base utility bills are in the “must pay” category. Commanders and managers know that they will get the money necessary to pay them—which reduces the incentive for reducing consumption. The Air Force believes that it is in relatively good shape in meeting its goals for reducing water consumption and expanding renewable energy. However, there is a recognition that decisions regarding energy and environmental projects continue to be made on an ad hoc basis, which leads to suboptimization. For example, the Air Force has leased land at Nellis Air Force Base on which a contractor has built a photovoltaic (PV) electricity system, ostensibly to meet renewable energy and energy security goals for the base. However, the PV electricity is not connected to the base, but instead goes directly to the grid, and there does not appear to be funding available or the right incentives to make the connection to the base. Technology tends to be applied where it can be applied, as opposed to where it should be applied. Ottoman stated that there needs to be a macro model that could lead to a more holistic approach to energy and environmental decision making throughout the Air Force.

Much of the discussion following this presentation revolved around the issue of fragmented decision making and suboptimization. One participant commented that DuPont’s energy initiatives also started as scattered and ad hoc efforts, and only coalesced into a coherent program over time. The Office of the Deputy Assistant Secretary of the Air Force for Energy has only been in existence for about 2 years, with a small staff and minimal contractor support. The biggest concern may be the lack of visibility of energy issues at headquarters outside of the civil engineering community. There are no “blue-suit” logisticians; leadership is needed to address process energy. Several participants asserted that energy use must be translated into cost in order to influence the acquisition community.

Several workshop participants also commented on issues related to metering. Metering will provide quicker and more accurate data on energy consumption to managers. The Empire State Building in New York City was renovated several years ago and meters were installed. Businesses located in the building competed to reduce their electricity consumption. The lesson was that energy use should not be viewed as an isolated island—there is a whole community involved. Other comments related to funding for submetering, which will be needed in order to tackle industrial process energy. Submetering would have to be funded by maintenance accounts rather than civil engineering accounts. However, meters would not have to remain indefinitely at a single site. It should be possible to save money by moving meters around from site to site in order to verify the value of investments as part of a research and development process.

3

Wrap-Up Discussion

The final day of the workshop was devoted primarily to general discussion and to distilling and considering the main points that had been presented. The discussion involved the following topic areas: (1) management and leadership, (2) budgets and funding, (3) information resources, (4) metrics, (5) culture change, (6) personnel and training, and (7) investment opportunities.

MANAGEMENT AND LEADERSHIP

To most participants who spoke at the workshop, it appeared that the Air Force has a solid overall energy strategy and that the representatives from bases such as Arnold AFB and Tinker AFB have a nuanced and well-thought-out understanding of energy usage in general and of process energy and opportunities for addressing the associated challenges without impact to the mission. With the right vision from leadership and access to resources, the facility managers who addressed the workshop appear to be well positioned to implement improvements. Many participants were impressed with the progress that the Air Force has made on its energy goals. Stimulated at least in part by the successful efforts of civil engineers who have demonstrated that a reduction of energy waste in facilities augments mission capability, most participants seemed to think that everyone is trying to support the energy goals of the Air Force.

The primary criteria on which the Air Force is judged are combat readiness and mission capability; reducing energy use can contribute to energy security and can save money that can be used to improve readiness, but reduction in energy use per se is not a primary objective, especially if it conflicts with maintaining mission capability. Many speakers noted that energy reduction will not stand a chance if it stands alone; it needs to be a part of every operational decision. Energy projects that have a long payback time are particularly hard to fund and sustain, in part because the tenure of any particular commander is typically short compared to the payback time. For example, it was noted that paint hangars are expected to last a long time and should be able to sustain long-term investments.

It was a general view among participants who spoke at the workshop that Air Force leadership has stepped up to spend on reducing energy use in buildings in response to federal mandates, but there have been no comparable goals or mandates addressing the fuel or industrial process aspects of the problem, despite the likelihood that the lower-hanging fruit and biggest potential reductions are on the aviation side. There appears to be no guidance that puts an emphasis on energy efficiency and conservation in decisions related to process energy use. Several speakers asserted that the procurement process needs to be adjusted in order to better reflect total life-cycle O&M costs for equipment purchases. Often, more efficient equipment has a higher upfront cost but can deliver significant energy savings over its useful life. In general, many participants thought that the Air Force has been forced to take an ad hoc approach to energy efficiency and conservation improvements, reacting to available funding or available resources to support a specific effort. Sometimes, projects can counteract each other and cumulatively miss the "big picture" objective. For example, one participant pointed out that process energy needs are not necessarily compatible with the installation of nonfirm renewable power generation.

Several participants believed that the Air Force should consider taking a more holistic approach to developing a long-term strategy for addressing the energy cost and delivery of buildings and facilities for a particular base or depot, regardless of current funding sources. They noted that this could also be done within the context of local and regional energy issues and opportunities. In that way, a base could collaborate with local groups to implement an overarching strategy when and if it became appropriate to pull in other non-Air Force resources, and simultaneously the base could apply available Air Force resources to projects within a larger strategic plan for the facility as they become available. Energy efficiency is likely an area that would provide a significant ROI. Moreover, DuPont has found that there are ways to save money by streamlining the project-management process itself. Thus the problem may be related less to a lack of funds and more to insufficient focus on energy by the allocation process. Several speakers noted that the way in which energy plays into the Air Force base decision process needs to be codified.

BUDGETS AND FUNDING

A budget is an expression of values and priorities at a given time. A variety of government budget authorities and of public and private mechanisms are available to fund energy-reduction projects. These include the following:

- *Operations and maintenance ("3400") funds, used to recapitalize infrastructure.* The Air Force has historically funded this at less than 2 percent of plant replacement value, compared with a typical private-industry investment of 6 to 8 percent.

- *Research, development, test, and evaluation ("3600") funds, controlled by A3 (Operations) of which approximately $300 million is to sustain the test program infrastructure.* It does not appear that energy- and water-conservation projects have received support from this community. Also, energy and water conservation are not included as part of the discussion in test infrastructure/equipment construction, restoration/modernization, sustainment and demolition.
- *Milcon ("3300") funds for new construction and major renovation and Working Capital Fund Capital Investment Program (WCF CIP), controlled by A4 (Installations and Logistics).* The U.S. Army Materiel Command has designated 6 percent of its CIP for infrastructure renewal projects, in compliance with guidance from the National Defense Authorization Act of 2007 (Public Law No. 109-364). The Air Force does not appear to have interpreted this as a "hard and fast" requirement. Although there are recent successes of including energy and water conservation in some infrastructure/equipment upgrades, the concept is not fully integrated into the Depot Maintenance Activity Group framework—which consists of infrastructure/equipment construction, restoration/modernization, and sustainment and demolition.
- *Third-party funding, a financial contract in which a company saves the Air Force energy and/or water over a period of years, and for payment over the term, keeps the savings.* These include Energy Savings Performance Contracts and Utility Energy Savings Contracts. The Air Force expects to rely more heavily on third-party funding for energy projects in the future as internal funding sources shrink.

No Air Force budget line is specifically devoted to energy. Several workshop participants expressed the idea that these diverse sources tend to lead to a fragmented, ad hoc approach to energy projects that lacks a long-term vision, is suboptimized, and can lead to "color-of-money" constraints. Most participants felt that the Air Force's use of ESPCs, as required by presidential order, is a good mechanism for providing funding for infrastructure and efficiency improvements in the absence of other funding sources. ESPCs accomplish the goal of reducing energy usage (intensity), although they do not result in cost savings to the Air Force over the near term and may actually result in cost increases if a contract needs to be "bought out" due to base closure or shifting priorities. Nonetheless, absent other funding sources, they appear to be a valid mechanism and worth implementing.

INFORMATION RESOURCES

Several workshop participants noted that Air Force personnel should look for opportunities to identify the processes that offer the largest potential ROI for energy-reduction and also should seek opportunities to leverage what they know and how they do what they do through collaboration and networking with subject-matter experts and consortia of organizations concerned with making processes better, faster, cheaper, safer, and more energy-efficient. This collaboration could be institutionalized. Examples include the Construction Industry Institute at the University of Texas at Austin, which brings together experts from many major companies, academia, and government to discuss technical concerns. The Air Force could consider stimulating an analogous interaction with industry, academia, and other agencies on a continuing basis. The key to the success of such collaborations is a continuing interaction, with a focus on accomplishment. In this environment, all participants can receive benefits that far exceed participation costs. Networking can also be done remotely. Many participants agreed that there is a reservoir of goodwill and desire to help the country in many major companies, especially if the information provided will be used on a noncompetitive basis.

The technical underpinnings for such an interaction are in place. For example, DuPont has a list of best practices that it used when it increased output while decreasing energy input. Robins AFB started an energy and conservation forum in 2008 to discuss energy-reduction efforts in the AFMC, and further forums are planned. But many participants noted that the primary emphasis of such efforts has been on the civil engineering (CE) side rather than on the process side. These efforts can be folded into—and serve as foundation for—Air Force participation. Finally, the Advanced Manufacturing Office within DOE's EERE has been working with companies to improve processes for 30 years. All of the resulting documents are free and available on the web. The Federal Energy Management Program in DOE's EERE offers consulting services, with experts in various process technologies, and evaluation software tools.

Since energy, water, and waste issues often scale beyond the installation perimeter, several participants stressed that it is important for base commanders to get involved with the broader community—for example, by participating in energy-use groups. Such participation has already saved money at Tinker AFB. The larger the set of parameters over which a solution is optimized, the less likely one is to have a suboptimized, inefficient solution. However, participants noted that it also should be recognized that each Air Force installation is unique and may have its own special requirements. Awareness of new technologies and ways of doing things is important. Training and software tools are available, but they must be adapted to local procedures. It is becoming increasingly feasible to develop computer-based models of a facility that provide the information needed to plan and assess the impact of emerging energy, water, and waste technologies.

Energy efficiency, water conservation, process improvement, smart grid, smart buildings, facilities, and cities are all major engineering research topics today. Thus it was not surprising to hear from industry speakers that their research staff is intimately involved in improving energy productivity. Several participants noted that the Air Force Research Laboratory is well positioned to help the Air Force improve its energy usage and has published a description of its energy focus. However, it appeared to several participants that the relationship between the depots and AFRL is limited. They thought that AFRL could be tasked with helping the depots. This tasking would be consistent with a focus on next-generation technologies. Improvement of industrial processes is a fertile field for innovative engineering research. For example, an AFRL-funded industry partnership developed improved high-speed drill bits that lasted longer and saved water.

Some participants noted that a second tasking for AFRL could be to serve as the primary interface between the Air Force and the DOE national laboratories. The Air Force could take advantage of these resources, but the various DOE laboratories compete with each other for funding. Choosing the right avenue of collaboration requires that the users of the technology be knowledgeable about the strengths and weaknesses of the various programs. The staff members of AFRL are the technical peers of the DOE scientists and engineers and are likely in the best position in the Air Force to provide the interface needed to use the national laboratories' capabilities effectively.

Several participants were of the opinion that a third tasking for AFRL could be to form a closer relationship with Air Force energy managers. Much of the ad hoc approach to energy at Air Force installations is due to the fact that installations do not have the technical capability to assess technologies and systems with existing staff and often rely on open-source information without due diligence to the overall Air Force approach. For example, an industry provider may approach the CE lead at an installation with a valid technology for battery storage on a site, but the local CE lead might not have the capability to assess this across all battery technologies or similar technologies (e.g., flywheels).[1] There are many best practices to identify and share, such as Arnold AFB, Tennessee, managing its workload by moving high-energy-use testing to off-peak hours (nighttime) to reduce costs. One suggestion was to compile examples from both the Air Force and industry into a best-practices handbook that could be useful in sharing those experiences. Other participants indicated that there are likely opportunities to install energy saving measures such as soft starts and variable frequency drives on equipment, and that an inventory of such opportunities should be conducted on a facility-by-facility basis.

METRICS

Many workshop participants agreed with the idea that data—and therefore appropriate metrics—are critical for various purposes such as the following: for raising awareness of energy use, driving culture change, making the business case for investments, and presenting the value proposition to commanders that energy use can be reduced while improving mission capability at the same time. However, as metering and data collection are improved in order to understand energy usage, it is important to understand what will be done with the resulting information in order to avoid

[1]The three taskings may require some restructuring of how AFRL operates since energy issues cut across AFRL directorates.

”collecting data for data’s sake.” One participant noted that developing a data-collection and data-management plan to inform the overall objectives can avoid the challenge of swimming in data that are not meaningfully used.

Data are also important in order to understand actual performance versus projected performance. Often, systems underperform compared to expectations, and documenting why this occurs is important for improving future projects. Also, one participant stated that people involved in a specific project can become “project champions” and at times can lack objectivity. Having a process to go back and assess actual performance to inform future project and funding decisions is important. Several participants were of the opinion that in the next 10 years, metering of energy use—at least at the building level—will indicate new ways to improve and will “break the waves” for more detailed energy analyses at the individual process level. Many stated that the Air Force should consider adopting the Navy Geospatial Energy Module/Energy Dashboard, which can roll energy usage from a building to the facility level and provide clear energy information to users compared to an established baseline. The Air Force’s advanced meter reading system as presented at the workshop may perform a similar function, but participants commented that it would be worth comparing best practices with the Navy so as to avoid re-creating a system that already exists.

A frequently expressed view by the participants was that the Air Force needs better energy-use metrics that measure the right things. The most commonly used metric for energy intensity is British thermal units per square foot (which should be reported in joules per square meter, since the U.S. government has committed to the use of the metric system). This metric is driven by the externally mandated goals. It is obviously a metric that focuses on building shells and personnel habits. As such, it has stimulated the DoD to invest in energy efficiency in order to meet mandated improvements in that metric. Largely, the investments appear to have been made in ways that enhance both energy security and mission effectiveness. But one participant noted that this metric is flawed in three important ways:

- *It rewards lightly used and lightly serviced buildings.* In the extreme, it could serve as an impediment to the destruction of obsolete and unsafe buildings. More importantly, however, it rewards light rather than optimal use of a facility. It counts the consolidation of activities and/or surges in personnel or mission activities as an increase in energy intensity, whereas these are actually actions that can reduce the energy required to meet the mission effectively.
- *The DoD maintains industrial facilities that produce products.* An example is the Air Force depots that refurbish the nation’s military aircraft. Industrial experience suggests that there is significant energy and cost savings that could be achieved by a serious look at these processes. The metric used, however, stimulated a funding focus on facilities, thereby limiting the funding available to address energy-intensive processes and the equipment that leads to that inefficiency.

- *Finally, a key responsibility of the military is to project military force.* This activity requires fuel. The energy-intensity metric is obviously irrelevant to effective fuel use.

Several participants agreed that the important issue raised in this discussion is that the Air Force would benefit if it had a coherent and transparent set of metrics that related energy use to the accomplishment of the mission—the desired metric for making a value proposition to decision makers and commanders. For industrial processes, this might be energy used per unit of product (for example, General Motors uses megawatt-hours per vehicle). One way of accounting for surges in activity might be to normalize the existing energy-intensity metric to the number of direct labor hours. The current energy-intensity metric, albeit flawed, demonstrates that metrics can stimulate beneficial behavior. Many participants believed that the Air Force should consider concentrating more effort on developing a set of metrics that permit it to improve its mission capability while lowering energy use and cost.

Another view stated that it is also important to recognize that in some areas in which process energy is central to the mission, opportunities for large-scale reductions in energy usage or savings are not feasible. This consideration needs to be reconciled with established metrics such as energy intensity. Energy intensity as a singular metric is probably not appropriately applied to facilities with high process energy needs required to meet their mission.

CULTURE CHANGE

Many workshop participants were of the opinion that the Air Force is making good progress toward metering individual facilities; however, it is imperative that the information get back to the individual users of that facility, who are in the best position to enact small, incremental changes. The Air Force estimates that behavior change can result in a 2 percent improvement in energy usage for buildings. However, one participant stressed that the overarching goal should be toward a culture shift at all levels of the organization—"culture" being defined as behaviors that individuals engage in even when no one is looking.

Another participant noted that it is critical that Air Force uniformed personnel in the field participate in shaping the specifics of strategies to reduce energy use, and that procedures not be simply dictated from headquarters by people who have no experience in the field. Several speakers noted that two possible paradigms for how to integrate energy awareness into corporate-wide thinking are illustrated by efforts already made to promote pollution prevention and safety. Air Force instructions mention pollution prevention and safety, but not energy use. There could be a reward system for personnel in the field who come up with good ideas for saving energy. Several participants noted that considering improvements in energy management as a criterion for promotion for facility managers could also help drive cultural change.

Culture change needs to occur throughout the organization, and must be supported by the upper level of leadership. Blindly working toward achieving metrics and milestones does not necessarily meet the underlying goals.

PERSONNEL AND TRAINING

Many participants expressed the idea that it is important for individuals in the Air Force at all levels of management and responsibility to be aware of the importance of addressing energy-security/-surety and costs, and that, at times, improving efficiency and reliability can result in enhancement to the mission. Some participants suggested that having mandated energy training throughout the Air Force might be a driver toward greater understanding of the problem. Classes in energy-related topics are already offered by the Air Education and Training Command. Another suggestion was to have energy efficiency written into the job description (and performance evaluation) of process managers and that they receive appropriate training. Yet another suggestion discussed by participants was a graduate degree or certificate that could be offered by the Air Force Academy or the Air Force Institute of Technology with a focus on energy.

It was demonstrated in several presentations that the acquisition of new technologies and infrastructure provides a great opportunity for improvements in energy efficiency and long-term energy reduction. A key target for improving energy awareness is the acquisition community, to get life-cycle energy use to be one of the criteria on which acquisition decisions are made. One participant noted that an example target group is the Logistics Officers Association. There is no codified knowledge base for process equipment at depots. An example is the lack of maintenance manuals written to support test facilities at Arnold AFB. One suggestion was that progress might be made through working with the Society of Maintenance and Reliability Professionals.

INVESTMENT OPPORTUNITIES

Several speakers noted that the civil engineering community has shown the Air Force that energy-reduction projects are a good investment—typically returning $2 in savings for every $1 invested. One speaker noted that specific processes such as painting offer opportunities for improvement (as the General Motors presentation showed), but there is no budget for it. The CE community typically does not own either the industrial process or the budget. Participants noted that other processes that are good candidates for efficiencies are those that generate or transfer heat or involve rotating equipment. One participant noted several potential areas for future Air Force investment:

- Work process design and associated training and audit protocols focused on business effective energy management.

- Standardization of all common, repetitive processes such as machining, parts/equipment cleaning, painting, etc. across all sites.
- Engineering evaluation of rotating and heat exchange equipment to establish life cycle energy use and operating costs.
- Formal assessments of current operations vs. standard protocol to identify short and long-term improvement actions and projects (see Appendix E for possible areas to consider).

Appendix A

Biographical Sketches of Committee Members

Kenneth E. Eickmann is the deputy director of the University of Texas Center for Energy Security and senior research fellow for all energy related matters at the University. In December 2009, he facilitated a national forum to identify strategic energy goals for the U. S. Air Force and the nation. In 2010, Lt. Gen. Eickmann chaired an Air Force Installation Energy Study designed to determine how best to ensure military installations have energy for mission critical capabilities. Eickmann currently serves on the Military Advisory Board for the Center for Naval Analyses, which completed and published a study in October 2011, laying out the national security imperative to reduce U.S. oil dependence. General Eickmann is a Registered Professional Engineer and is certified as an Acquisition Professional in Acquisition Logistics, Program Management and Systems Planning, Research, Development & Engineering. He is also a recognized expert in propulsion technology and has published several papers in technical journals in the United States and overseas. Following his retirement from the United States Air Force in 1998, he served as the director of the Construction Industry Institute (CII) at The University of Texas (UT) at Austin, where he led a collaborative effort by engineering and construction owners, contractors, and academia to improve one of the nation's largest industries. General Eickmann's accomplishments include selection as a Distinguished Engineering Graduate of the University of Texas; selection for membership in the National Academy of Construction; and selection as chairman of a general officer red team formed to review logistics transformation efforts of the U.S. Air Force. He was also a member of a National Research Council committee formed to provide an independent evaluation of the feasibility of achieving the science and technology requirements implied in the National Aerospace Initiative. Eickmann currently serves as the state vice chairman of the Texas Engineers Task Force for Homeland Security. Lt. Gen. Eickmann (ret) is a past member of the Air Force Studies Board and past chair of several NRC studies, including *A Review of United States Air Force and Department of Defense Aerospace Propulsion Needs* (2006) and *Improving the Efficiency of Engines for Large Nonfighter Aircraft* (2007).

Robert E. Hebner, Jr., is the director of the Center for Electromechanics and associate director for technology of the Center for Energy Security, both at the University of Texas at Austin. Throughout his career, Hebner has served on numerous technical committees that develop voluntary standards for the electric utility industry. His personal research focuses on smart grid technologies, microgrids, renewable energy, and energy storage. He is an active contributor to the Pecan Street program that is helping to gather the information needed to design a smart grid architecture that is attractive to both consumers and industry. Hebner has had extensive experience in technical collaborations, being former chair of the Board of the Center for Transportation and the Environment and chair of the Electric Ship Research and Development Consortium. He is also a past member of the Board of Directors of the IEEE. He has been selected as vice president elect for the IEEE with responsibility for all of the IEEE's technical activities. The combination of the Pecan Street and IEEE activities has provided opportunities for unique insight into smart grid and smart city activities in the United States, Europe, and Asia. He has applied this knowledge to military energy activities. He was a founding member of the Electric Ship Research and Development Consortium. He has made significant contributions to the design and operations of ship power systems, which are isolated microgrids. Research in the two centers has led to modeling techniques for power systems for ships, forward bases, and military bases in the United States. In addition, he has been a member of an Air Force study team that assessed the energy security of Air Force bases. Before joining the University of Texas, he spent many years at the National Institute of Standards and Technology (NIST), culminating his time there as acting director. He also worked in the Office of Management and Budget and at the Defense Advanced Research Projects Agency. Throughout his career, Hebner has been active technically, having received a Ph.D. in physics and having authored or coauthored more than 150 technical papers and reports. He is a fellow of the IEEE.

Thom J. Hodgson is the James T. Ryan Distinguished University Professor, an Alumni Distinguished Research Professor, co-director of the Operations Research Program, and director of Graduate Programs of Engineering-On-Line at North Carolina State University (NCSU). He served as director of the Integrated Manufacturing Systems Engineering Institute at NCSU ('95-'11); director of the Division of Design and Manufacturing Systems at the National Science Foundation ('91-'93); head of the Industrial Engineering Department at NCSU ('83-'90); professor of Industrial & Systems Engineering at the University of Florida ('70-'83); operations research analyst at Ford Motor Company ('66-'70); and an officer in the U.S. Army ('61-'63). He is a fellow of IIE and INFORMS, and a member of the National Academy of Engineering. He is the author or co-author of over 80 journal articles and book chapters. He served as associate editor, departmental editor ('81-'84, '88-'91), and editor-in-chief ('84-'88) of *IIE Transactions*. He served as a member of the U.S. Army Science Board ('94-'00).

Gwen P. Holdmann is the director of the Alaska Center for Energy and Power (ACEP), which is an applied energy research program based at the University of Alaska Fairbanks emphasizing both fossil and renewable/alternative energy technologies. ACEP is a highly interdisciplinary program with over 30 affiliated faculty, spanning a wide range of energy-related disciplines. Prior to joining the University of Alaska, Holdmann served as the vice president of new development at Chena Hot Springs Resort near Fairbanks. While at Chena, Holdmann oversaw the construction of the first geothermal power plant in the state, in addition to numerous other innovative energy projects ranging from hydrogen production to cooling a 10,000 ft^2 ice museum year-round using 150°F hot water. Holdmann moved to Alaska in 1994, shortly after graduating from Bradley University with an M.S. in physics and mechanical engineering. Holdmann has been the recipient of several awards throughout her career, including an R&D 100 award, Project of the Year from Power Engineering Magazine, and the Alaska Top 40 Under 40 Award.

Carroll N. LeTellier, a member of the National Academy of Engineering (NAE), was involved in the early design phases for the new Cooper River Bridge. Other significant projects he helped lead include the design and building of the Tennessee Tombigbee Waterway, the Fort McHenry Tunnel in Baltimore, Locks and Dam 26 on the Mississippi, and multimillion dollar improvements to the physical and technical security of 44 U.S. embassies worldwide. A 1949 graduate of the Citadel, LeTellier served for 27 years with the U.S. Army Corps of Engineers. He then joined Sverdrup Corporation as vice president, where he served for 25 years until his retirement in 2001. The NAE cited LeTellier for "leadership in the planning, design and construction of major infrastructure and military facilities that meet and serve the highest societal values." LeTellier has had a lifelong connection with engineering and the Citadel. His father, Louis S. LeTellier, was head of the Citadel's civil engineering department for many years and served as acting president of the college after the retirement of General Charles P. Summerall in 1953 until the arrival of General Mark Clark in 1954.

James B. Porter, Jr., was chief engineer and vice president of engineering and operations for DuPont until his retirement in September 2008. He joined the company in 1966 as a chemical engineer in the Engineering Service Division (ESD) field program at the Engineering Test Center in Newark, Delaware. He left the same year for a tour in the United States Army and returned in April 1968 as a technical services engineer at DuPont's Chattanooga, Tennessee, fibers plant. Porter was named vice president of engineering on November 1, 1996. He then became vice president of Safety, Health & Environment and Engineering on February 1, 2004. Porter assumed the position of chief engineer and vice president, DuPont Engineering and Operations on July 1, 2006. He has served as chair for the Construction Industry Institute (CII) and he was the 2004 recipient of CII's Carroll H. Dunn Award of Excellence. In 2005 he received the Engineering and Construction Contracting Association Achievement Award and in 2007 he was honored with the Society of Women Engineers Rodney D. Chipp Memorial Award. In 2008 he was the first recipient of FIATECH's "James B. Porter, Jr. Award for

Technology Leadership." He is a member of several boards of directors and is on the Argonne National Laboratory Board of Governors. Today, Porter is the founder and president of Sustainable Operations Solutions, LLC, which provides consulting services to help companies make significant and sustainable improvements in workplace safety, process safety management, capital effectiveness, and operations productivity. He received a B.S. in chemical engineering from the University of Tennessee. Porter is a current member of the Board on Infrastructure and Constructed Environment.

Scott E. Sanders is the current vice president for strategic innovation for Wyle Laboratories, Inc. He is responsible for the cultivation and infusion of innovative science, technology, and processes that overlap energy, environmental, infrastructure, and business considerations. His focus is on solutions that support the DoD marketplace and that facilitate rapid and agile responses to the changing national security environment and the associated culture change methodologies. Sanders has been with Wyle for over 25 years and he previously led a $2 billion contract effort supporting the Defense Technology Information Center, where "operational energy" was infused into the construct of the contract in response to national level emphasis and focus on this critical area. He was responsible for the technical evaluation of rapid responses to deployed forces and the analysis of their merit for distribution to all services. He has worked with several non-profit associations on energy and water issues, such as the American Council on Renewable Energy (ACORE) and the International Renewable Energy Agency (IRENA), as well as several major universities. Sanders is a drilling reservist and holds the rank of Rear Admiral in the United States Navy. He served as Vice Commander of U.S. Naval Forces in Bahrain for 3 years and was the first drilling reservist since WWII to command an at-sea task force (CTF-151 Counter Piracy). He also has served as the Deputy Commander for the largest U.S. Navy Fleet (2nd Fleet) and is currently assigned to the Joint Staff. He has a broad perspective on energy, water usage, and energy- and water-reduction technologies and their application to forward deployed as well as CONUS-based forces. Sanders also has a solid understanding of what partner nations (Middle East and East Africa) are developing and their associated energy security approaches that relate to reduced energy usage and/or reduced dependency on petroleum sources.

Appendix B

Workshop Agenda

Energy Reduction at U.S. Air Force Facilities Using Industrial Processes:
A Workshop

November 5-7, 2012
The Keck Center of the National Academies
Room 110
500 Fifth Street, NW
Washington, DC 20001

MONDAY, NOVEMBER 5

0900 **Welcome and Introductions**

- Lt Gen (ret) Ken Eickmann, Workshop Committee Chair

0930 **Vision for the Workshop**

- Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy, Office of the Assistant Secretary of the Air Force for Installations, Environment and Logistics

1000 **Break**

1015 **OSD Initiatives**

- Joseph Sikes, Director of Facilities Energy Privatization, Office of the Deputy Under Secretary of Defense for Installations and Environment

1115	**Manufacturing Industry Initiatives**
	➢ Paul Bollinger, Director, Boeing Energy
1215	**Continue Discussions *with Lunch Available***
1300	**Air Force Materiel Command Initiatives**
	➢ Col Douglas Wise, Chief, CE Operations and Readiness Division, HQ AFMC/A7O ➢ Col Stephen Wood, Vice Commander, Air Force Sustainment Center ➢ Kirk Rutland, Technical Director, Test Sustainment Division, Arnold Engineering and Development Complex ➢ Cameron Stanley, Advanced Power Technology Office, Air Force Research Laboratory
1600	**Break**
1615	**Workshop Committee Feedback to Day 1 Presentations**
	➢ All
1700	**Adjourn**

TUESDAY, NOVEMBER 6

0900	**Navy Initiatives**
	➢ Thomas Hicks, Deputy Assistant Secretary of the Navy for Energy ➢ Sandrine Schultz, Energy Program Manager, Commander, Navy Installations Command
1000	**Break**

1015 **Army Initiatives**

- John Dwyer, Deputy Chief of Staff for Logistics (G4), Army Materiel Command

1115 **DOE Initiatives**

- Timothy Unruh, Program Manager, Federal Energy Management Program, Office of Energy Efficiency and Renewable Energy

1215 **Continue Discussions *with Lunch Available***

1315 **Manufacturing Industry Initiatives**

- Al Hildreth, General Motors
- James Porter, Jr., Independent Consultant
- Roger Weir, Energy Manager, ATK Aerospace Systems

1600 **Workshop Committee Feedback to Day 2 Presentations**

- All

1700 **Adjourn**

WEDNESDAY, NOVEMBER 7

0900 **HAF Initiatives**

- Col Gregory Ottoman, Chief, Environment and Energy Division, Office of the Deputy Chief of Staff for Logistics, Installations, and Mission Support

1000 **Break**

1015	**General Discussion with Participants to Include Next Steps**
	➢ All
1200	**Continue Discussions *with Lunch Available***
1300	**Adjourn**

Appendix C

Workshop Participants

Energy Reduction at U.S. Air Force Facilities Using Industrial Processes:
A Workshop

November 5-7, 2012

The Keck Center of the National Academies
Room 110
500 Fifth Street, NW
Washington, DC 20001

COMMITTEE MEMBERS

Lt Gen (ret) Kenneth E. Eickmann, *Chair*
Robert E. Hebner, Jr.
Thom J. Hodgson
Gwen P. Holdmann
MG (ret) Carroll N. LeTellier
James B. Porter, Jr.
RADM Scott E. Sanders

NRC STAFF

Terry Jaggers, *AFSB Director*
Carter Ford, *Program Officer*
Gregory Eyring, *Rapporteur*
Dionna Ali, *Senior Program Assistant*
Marguerite Schneider, *Administrative Coordinator*

SPEAKERS

Kevin Geiss
Deputy Assistant Secretary of the Air Force for Energy
Office of the Assistant Secretary of the Air Force for
Installations, Environment and Logistics

Paul Bollinger
Director
Boeing Energy

John Dwyer (via VTC)
Deputy Chief of Staff for Logistics (G4)
Army Materiel Command

Robert Gemmer
Technology Manager
U.S. Department of Energy

Thomas Hicks
Deputy Assistant Secretary for the Navy for Energy

Al Hildreth
Company Energy Manager
General Motors

Col Gregory Ottoman
Chief, Environment and Energy Division
Office of the Deputy Chief of Staff for Logistics,
Installations, and Mission Support

Kirk Rutland
Technical Director, Test Sustainment Division
Arnold Engineering and Development Complex

Sandrine Schultz
Energy Program Manager
Commander, Navy Installations Command

Joseph Sikes
Director of Facilities Energy Privatization
Office of the Deputy Under Secretary of Defense
for Installations and Environment

Cameron Stanley
Support Contractor
AFRL/RXS-APTO

Timothy Unruh
Program Manager, Federal Energy Management Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Kenneth Walters
Chief, Measurement and Analysis Division
Air Force Civil Engineer Center – Energy
Air Force Materiel Command

Roger Weir
Energy Manager
ATK Aerospace Systems

Col Douglas Wise
Chief, CE Operations and Readiness Division
HQ AFMC/A70

Col Stephen Wood
Vice Commander
Air Force Sustainment Center
Air Force Materiel Command

GUESTS

Ron Descheneaux
Senior Energy Analyst
Air Force

Fred Eng
Chief, Energy Branch
Air Force

David Fort
Energy Manager
HQ AFMC/A70S

Julie Fowler
Facility Engineer
USAF AFMC 76th Propulsion Maintenance Group

Darrin Kayser
Lead Associate
SAF/IEN (Booz Allen Hamilton)

Dan Mitchell
Energy Manager
U.S. Air Force

Theresa Norris
Test Support Division
Arnold Engineering and Development Complex
Air Force Materiel Command

Elisa Shyu
Senior Consultant
SAF/IEN (Booz Allen Hamilton)

Appendix D

Presentation Abstracts

Speaker: Kevin Geiss, Deputy Assistant Secretary of the Air Force for Energy
Presentation Title: Vision for the Workshop

The U.S. Air Force is a leader in energy security with a history of innovation in identifying ways to reduce demand and increase the supply of energy. In the area of alternative fuels, the Air Force has worked for six years to certify aircraft on a range of alternative fuels including Fischer-Tropsch, Hydroprocessed Renewable Jet and Alcohol to Jet fuel types. Along the way the Air Force accomplished a number of “firsts” including the first aerial refueling, first supersonic flight, and first flight by an aerial demonstration team (the Thunderbirds). This certification has been shared with the aviation industry through the Commercial Aviation Alternative Fuels Initiative (CAAFI) and leveraged by airlines that now fly select routes on biofuel blends. Dr. Geiss’ presentation reviews the Air Force’s alternative fuel accomplishments and highlight areas of current and future research, testing and application. This includes on-going certification of aircraft on alternative fuels, months-long field testing of drone aircraft on biofuels and analysis of the long-term impacts of biofuels on engine components. Dr. Geiss will also discuss partnerships with other U.S. government and military entities, foreign countries and industry. These partnerships allow the Air Force to share its knowledge and expertise with the fuel-engine interface with outside organizations who can then bring their own knowledge and perspectives to the issue.

Speaker: Joseph Sikes, Director of Facilities Energy Privatization, Office of the Deputy Under Secretary of Defense for Instillations and Environment
Presentation Title: OSD Initiatives

This talk will highlight the following OSD initiatives:

- DoD Goals and Objectives
- 2011 Annual Energy Management Report (AEMR)--Status of Performance Metrics
- Validity of Performance Metrics
- What to expect in the Next Administration

Speaker: Paul Bollinger, Director, Boeing Energy, Boeing Defense, Space and Security
Presentation Title: Boeing Internal Resources Reduction Initiative

The Boeing Company is the world's largest and most diversified aerospace company with Commercial and Defense, Space & Security partners and customers in more than 90 countries. We have more than 172,000 employees and 86 million square feet of floor space. While Boeing is aggressively driving toward greater sustainability in all aspects of our business, this presentation focuses on our internal operations, manufacturing and office conservation initiatives. Boeing is on track to meet externally communicated five-year Environmental Targets for reductions in energy consumption, greenhouse gas, hazardous waste generation and water use, as well as an increase in recycling rate. In addition, Boeing has established a LEED Silver standard for all new construction and building refurbishments and utilizes industry tools and best practices like EPA ENERGY STAR programs to continuously improve the efficiency of sites and buildings. To ensure meeting Company goals, the enterprise Conservation Initiative is comprised of eight focus areas that are driven by specific strategies, goals, communications and monthly metrics at all levels from individual sites up to the headquarters in Chicago. Conservation Focus Areas include: Energy Conservation, Renewable Energy, Sustainable Site & Building Design, Solid Waste & Recycling, Hazardous Waste, Water Conservation, Fleet Management and Alternative Commuting. Conservation strategies have also been incorporated into our Lean practices and workshops across the enterprise. Other programs that help drive greater sustainability include empowering more than 6,000 Employee Involvement Teams across the company to improve efficiency and eliminate waste. The annual internal Conservation Awards Program recognizes excellence in ten sustainability categories. Boeing also competes for external awards and recognition and has been named an EPA ENERGY STAR Industrial Partner of the Year for the past two consecutive years. Boeing's commitment to environmental stewardship starts at the top. Jim McNerney, President and Chief Executive Officer, in response to Boeing being awarded the 2012 Partner of the Year Award, stated "This ongoing achievement showcases our employees' commitment to champion the environment in everything we do – from developing and building our products to improving the efficiency of the infrastructure that supports them. This recognition is a reminder that all of us need to do our part to reduce consumption and conserve energy."

Speaker: Col Douglas Wise, Chief, CE Operations and Readiness Division, HQ AFMC/A70
Presentation Title: AFMC Facility Energy Program

The DoD is the largest single user of energy in the US. In 2011, the DoD spent almost $20B on energy and the Air Force made up almost half of that amount. The vast majority of the Air Force's energy use is for aviation fuels with smaller amounts consumed in facilities/utilities and transportation energy. For AFMC, the figures for aviation and facilities/utilities energy are reversed. AFMC therefore is focusing on facilities/utilities energy. In addition, AFMC is falling short of Executive Order goals for energy and water intensity reduction. By 2015, it is estimated that AFMC will fall 10% short of the energy intensity goal. To close this gap, AFMC needs to look at loads not associated with the facility envelope. This type of energy is defined as Process Energy, which includes IT, labs, medical, and industrial energy. For AFMC, we are currently focusing on our large industrial complexes as they consume a significant portion of our energy. This energy is currently being termed Industrial Process Energy (IPE). In 2012, AFMC/A6/7 partnered with AFMC/A4 to initiate an IPE IPT. AFMC/A4 subsequently took the lead to develop an IPE action plan, which is currently under development.

Speaker: Col Stephen Wood, Vice Commander, Air Force Sustainment Center
Presentation Title: Air Force Sustainment Center: Process Energy Update

Col Steve Wood will discuss key aspects of Air Force Sustainment Center process energy. The discussion framework is provided so the audience can understand the Air Force and Air Force Material Command energy environment, and then AFSC's Energy & infrastructure portfolio supported by detailed data associated with AFSC installations; Tinker, Hill, and Robins AFBs. Follow-on emphasis is provided regarding AFSC/CC Energy Philosophy as well as accomplishment, challenges, enablers, and future focus for process energy reductions.

Speaker: Kirk Rutland, Technical Director, Test Sustainment Division, Arnold Engineering and Development Complex
Presentation Title: Energy Reduction: AEDC Perspective

AEDC is a primary ground test component within DoD's Major Range and Test Facility Base (MRTFB). As part of the MRTFB, AEDC's mission is to provide decision quality data for acquisition programs. It's extensive suite of test facilities are operated and maintained using Air Force RDT&E funding. Historically, approximately 92% of the energy consumed at AEDC is directly related to the test mission. Annual fluctuations in total energy demand are a product of the type and level of test workload. The majority of AEDC's test infrastructure was designed and constructed prior to 1980 and is heavily dependent on electrical power to create the required test environment. Energy efficiency was not a critical design component. While the Air Force has made significant AEDC infrastructure investments over the last decade, the focus was on developing and sustaining critical test capabilities driven by acquisition program requirements. Marginal improvements in energy consumption have been made but not tracked. AEDC is currently evaluating 14 different energy reduction proposals, but the RDT&E funding pressures prevent major investments for energy reduction initiatives. Since the AEDC test facilities are coded RDT&E, they are prevented from competing for USAF Energy funding.

Speaker: Cameron Stanley, Support Contractor, Air Force Research Laboratory
Presentation Title: Environmental and Energy (E2) Technology Programs

The Advanced Power Technology Office (APTO) is AFRL's post S&T RDT&E focus on facility power and energy demonstrations. APTO has performed several technology demonstrations at large facilities across the Air Force. Primarily, demonstrations have highlighted technologies in the following 5 technology focus areas: Renewable Energy Integration, Energy Storage, Hydrogen, Waste to Energy, and Advanced Energy Technologies. The APTO technology development process, which includes requirements gathering, technology selection, solution development, operational validation, and transition planning, provides energy technology solutions that meet the needs of the operational Air Force and demonstrates enhanced capability while reducing energy consumption and environmental impact. The lessons learned from testing and demonstrating these technologies can be leveraged to address process energy issues at Air Force depots.

Speaker: Thomas Hicks, Deputy Assistant Secretary of the Navy for Energy
Presentation Title: Department of the Navy Energy Program

No abstract submitted.

Speaker: Sandrine Schultz, Energy Program Manager, Navy Installations Command
Presentation Title: Commander, Navy Installations Command Navy Shore Energy Program Brief

No abstract submitted.

Speaker: John Dwyer, Deputy Chief of Staff for Logistics (G4), Army Materiel Command
Presentation Title: AMC Facilities Energy Program

AMC's Energy Program used four basic tenants: Planning - Put plans in place to drive down demand and costs; Commander Visibility and Emphasis - Commanders must have a good handle on their energy requirements and associated costs; Technology -include energy considerations in construction and renovation projects by applying technology solutions; Communication: Share successes and challenges. AMC uses opportunities to increase productivity and energy efficiency through the use of Sustainment, Restoration and Modernization (SRM) funds at installations such as Tobyhanna, AD, Adaptive re-use of older facilities at installations such as Anniston AD, and new construction to consolidated facilities with reduced energy footprint at Corpus Christi AD. AMC's estimates a total investment of $360M is required (~ 2-3 times AMC's annual energy expenditure) to meet its 30% energy intensity reductions goal by FY15. AMC will leverage available authorities to establish long-term public/private partnerships (Energy Savings Performance Contracts (ESPC), Utility Energy Services Contracts (UESC), Enhanced Use Lease (EUL), Power Purchase Agreements (PPA) to provide sources for private sector financing for AMC energy projects. AMC currently has six active ESPCs with total third-party investment > $88M and is actively pursuing third-party financing at four AMC Installations and one UESC execution at another. AMC's approach to third party financing will conduct detailed energy audits and evaluate industrial process efficiency as part of ESPCs and other third party financing opportunities to provide detailed evaluations of energy using systems. The systems include compressed air and the associated distribution system, motors, lighting, HVAC/building pressurization, boiler/steam system decentralization and other energy using systems such as refrigeration, melting furnaces, process ovens, cracking towers, welding operations. Measurement and verification (M&V) of energy performance through utility metering is paramount to provide an indicator of success for the third party financed projects.

Speaker: Timothy Unruh, Program Manager, Federal Energy Management Program, Office of Energy Efficiency and Renewable Energy
Presentation Title: Federal Energy Management Program Overview

No abstract submitted.

Speaker: Al Hildreth, PE, CEM, Company Energy Manager, General Motors
Presentation Title: GM's Robust Energy Management System

Energy use is a large, but mandatory, expense incurred by manufacturers or facility operators and contributes to Greenhouse Gas (GHG) emissions. At General Motors (GM), although our expenditure for energy is not a large percentage of our total cost, we do spend in excess of $1 Billion USD annually. GHG emissions from energy use represent over 7 million metric tons per year of GM's carbon footprint. Hence, a robust Energy Management business process is needed to meet the challenge for industry. Management of energy and carbon to reduce environmental impact has become important enough to be included in our business plan, similar to safety, people, quality, responsiveness, and cost. Following a model similar to EPA Energy Star's seven step approach, energy as an environmental element has been integrated into GM's business policy and model. Based on top level commitment and public goals to reduce energy and GHG by 20% from 2010 to 2020, GM uses its standardized Global Manufacturing System (GMS) to ensure that energy efficiency and conservation is properly managed through performance assessment, action plans, evaluating progress, and recognizing achievements. The methods used to integrate energy management into our business plan include dedicated resources at all levels in the organization. With people as one of our most important resources, having qualified energy leaders at the corporate, global, regional and site levels is key to our success. To implement initiatives a dedicated budget for systems and projects is required, similar to other areas of the business. Forecasting energy, establishing targets, implementing projects and processes, regular monitoring, and corrective action when required ensures timely adherence to meeting our energy and carbon goals. GM recognizes achievements internally with various processes – Plant energy performance recognition, employee suggestions, employee compensation tied to business results, and others. Also, GM's recognition of our energy performance externally includes many awards and recognitions – EPA Energy Star labels for 2 facilities, meeting Energy Star's Challenge for Industry for 54 plants globally over the past year avoiding $90 Million USD and 1.2 million metric tons of GHG emissions, and winning a 2012 Energy Star Partner of the year award in Energy Management, along with many global, regional, and local awards for protecting the environment.

Speaker: James Porter, Jr., Chief Engineer and Vice President Engineering and Operations, DuPont(Retired); Founder and President, Sustainable Operations Solutions, LLC
Presentation Title: Sustainable Energy Management-"An Industrial Perspective"

The primary focus of the presentation was what is an effective leadership model to embed energy management in an organization so they can *"Make Energy a Consideration In All We Do"*? The model currently practiced in DuPont was highlighted and an energy management Tool Box was outlined. Focus areas for dealing with process energy management as well as core considerations to lead a culture change were discussed.

Speaker: Roger Weir, Energy Manager, ATK Aerospace Systems
Presentation Title: ATK Energy Efficiency Initiatives

ATK is a Fortune 500 aerospace, defense, and commercial products company with operations in 21 states, the Dominican Republic, Puerto Rico, and internationally. World's top producer of solid rocket propulsion systems. World's largest producer of military ammunition. Leader in affordable precision weapons, propellants, and energetic. Leading brands in law enforcement and sporting ammunition. Leading brands in soldier systems, sporting, and hunting accessories. Provider of advanced composite structures, satellite components, and subsystems. ATK operates in 3 business units; Aerospace, Defense and Sporting. Enterprise-wide Energy Team formed in 2003, 24 locations participate on the corporate team. Emphasis is on communication and sharing of best practices and lessons learned. The Team has four "working groups" centered on: Lighting, Compressed Air, Steam, and Natural Gas. Working groups meet monthly to discuss issues impacting energy costs and efficiency. Team Mission: Manage Energy Costs and Consumption – Not just pay bills. Work with providers and regulators to control costs and maximize savings. Develop meaningful measures of energy performance. Facilitate implementation of cost effective energy projects. Encourage Communication, within locations and across all locations. Provide Forum to share Best Practices as well as Lessons Learned. Be a single source for all energy and energy related information. Track Green-House-Gas emissions and minimize carbon footprint. Cultivate increased energy awareness across all ATK employees. Team projects generate more than $2M in annual energy savings and total actual energy usage has been decreasing consistently for the past 3 years. Focus of many of the projects has been to identify waste, make use of it or eliminate it. Efficiency improvements have been included in many process improvement projects. Measuring energy usage and providing data and usage goals to operating areas has been a focus at several locations ATK has also been actively engaged with DOE to help develop new energy technologies to put wasted energy to use and optimize operation of renewable resources and electric storage.

Speaker: Col Gregory Ottoman, Chief, Environment and Energy Division, Office of the Deputy Chief of Staff for Logistics, Installations, and Mission Support
Presentation Title: Air Force Facility Energy Initiatives

The Air Force Facility Energy Program is focused on making sound fiscal investments, meeting Air Force mission requirements, and complying with numerous statutory goals and executive orders. The Air Force has made significant investments in energy and water conservations projects over the last 18 years that have reduced energy consumption by 35%. This translates into annual cost avoidance in FY11 estimated at $579M. While great progress has been made, the Air Force, along with the other Services, is challenged in meeting the aggressive mandates and goals. The Air Force is executing an investment strategy that combines direct appropriated funds investment along with third-party financed projects to conserve energy and water as well as increase production of renewable energy. Another initiative is significantly increased use of facility meters along with an advance meter reading IT system. While, this is mandated under EPACT 05 and EISA 07, it is also a key enabler in the Air Force energy program, helping to identify energy efficiencies and provide measurement and validation of previous efforts. The Air Force is in the early stages of establishing a "Net Zero" energy, water, and waste implementation strategy that integrates the on-going efforts in all three areas, while seeking to maximize conservation results, improve energy security, and minimize long-term environmental liabilities.

Appendix E

Energy Management Checklist

This document is intended to be used as a checklist for walk-through energy efficiency audits and assessments.

Steam Generators and Heat Transfer Fluid Heaters and Vaporizers

- Use Fuel Flow/Air Flow Control with Oxygen Trim
- Maintain Excess Oxygen Below 5%, Below 8% for Stokers
- Reduce Stack Temperature to 330°F for Sulfur Bearing Fuels
- Minimize Combustibles in Stack Gas and Ash
- Burn the Lowest Cost Fuel
- Apply the "Utilized Cost" of Coal
- Minimize the Use of Stabilizing Fuel If It Is Expensive
- Burn Non-hazardous Wastes in Boilers or Vaporizers
- Check Casing and Flue Gas Ducts for Air In-leakage
- Optimize the Soot Blowing Schedule
- Keep Internal Tube Surfaces Free From Deposits
- Check Boiler/Vaporizer Efficiency Regularly
- Recycle Wastewater Streams for Ash Sluicing
- Split Range Control of Fan Speed and Dampers
- Control Oil Tank Temperature at Minimum
- Automate Boiler Blowdown
- Install Blowdown Heat Exchanger
- Optimize Load Sharing Between Boilers and Vaporizers
- Operate Boiler Feed Pumps at Minimum Discharge Pressure
- Check Feedwater Heaters for Efficient Heat Transfer
- Reduce Deaerator Vent to <O.1% Water Flow or <0.5% Steam Flow
- Keep Steam Pressure and Temperature at Maximum If System Has Turbines
- Lower Steam Header Pressure If There Are No Turbines

Steam Users

- Eliminate or Find a Use for Vented Steam
- Install Jet Compressor to Make Low Pressure Steam Useful
- Shift Users to Lowest Header Pressure Possible
- Optimize Steam Balance with the Right Combination of Motors and Turbines
- Install Condensate Flash Tanks to Recover Low Pressure Steam
- Reduce Pressure of Heating Steam During Warmer Weather
- Use Turbines Instead of PRV's to Reduce Steam Pressure
- Adjust Steam Header Pressures to Maximize Turbine Work
- Close Turbine Hand Valves
- If Turbine Exhaust Must Be Vented, Vent Those Turbines to Atmosphere
- Install Smaller Turbine Nozzles
- Repair Steam Leaks
- Isolate Unused Steam Lines
- Eliminate Long Steam Lines with Low Flow
- Establish an Effective Steam Trap Maintenance Program
- Reduce Failed Steam Traps to <5% of Total
- Ensure Bypass Valve Around PRV's Is Not Leaking
- Return All Condensate
- Recover Waste Heat Wherever Possible
- Replace Steam Vacuum Jets with Mechanical Vacuum Pumps
- Be Sure Vacuum Jets Have the Correct Nozzle Size
- Operate the Minimum Number of Vacuum Jets
- Be Sure Vacuum Jets Have the Correct Steam Supply and Exhaust
- Check Actual Steam Consumption Against Design
- Check Turbine and Condenser Performance Regularly
- Keep All Steam, Dowtherm, and Condensate Lines Properly Insulated
- Provide New Heat Tracing as Electric, Not Steam
- Conduct a PINCH Technology Survey

Electrical Loads

- Buy New High Efficiency Motors Instead of Rewinding Failed Motors
- Install High Efficiency Motors for New Applications
- Change to Smaller Motors on Lightly Loaded Drives
- Challenge the Need for Every Motor Running
- Use Variable Frequency Drives If Flow Rate/Load Varies Widely
- Use Daylighting Where Possible
- Remove Lamps Where Illumination Is More Than Is Needed
- Promote Turning Off Lights and PCs When Not In Use
- Use Photocells, Timers, or Motion Detectors to Operate Lights

- Replace Incandescent Lamps with Fluorescent, Sodium Vapor, or Metal Halide Fixtures
- Replace Safety Shower and Fire Alarm Incandescent Lamps with Compact Fluorescent Lamps
- Replace Fluorescent Ballasts and Lamps with High Efficiency Electronic Type Ballasts and T8 Lamps
- Request a Lighting Survey
- Clean Light Fixtures to Improve Efficiency/Light Levels
- Provide Electric Tracing Rather Than Steam Tracing
- Provide Controls on Self-Limiting Electrical Tracing
- Maintain Heat Tracing Thermostats and Controls
- Do Not Provide Heat Tracing For Freeze Protection on Lines 6" or Larger
- Keep Electrical Equipment Cool

Electrical Power Distribution

- Buy All Electricity Under One Contract
- Take Advantage of Utility Incentives for Demand Side Management
- Request an Interruptible Electrical Contract
- Have a Load Reduction Plan to Avoid Setting New Electrical Peaks
- Take Advantage of Utility Incentives for Demand Peak Shaving
- Use Diesel Generators to Shave Peaks
- Increase Turbine Generator Load to Shave Peaks
- Transfer Loads from Motors to Turbines to Shave Peaks
- Avoid Setting Peaks by Cycling Nonessential Equipment
- Run Nonessential Equipment and Batch Processes During Off Peak Hours
- Delay Starting Motors Until a New Peak Can Be Avoided
- Switch Large Motors Quickly to Avoid Setting a New Peak
- Install a Power Monitoring System to Enable Load Management
- Trend Plant Loads to Avoid Adding Unnecessary Distribution Equipment
- Analyze Power Usage to Identify Energy Reduction Opportunities
- Install Capacitors to Increase Power Factor
- Install Solar Photovoltaic Systems for Small Remote Loads
- Specify High Efficiency for New Power Transformers

Refrigeration

- Allow Condenser Pressure to Drop With Reduced Cooling Water Temperature
- Control Condenser Pressure to Reduce Horsepower
- Vary the Hot Gas Bypass Control Set Point With Condenser Pressure
- Monitor Energy Consumption Per Ton to Detect Poor Machine Performance
- Increase Chilled Water Delta T Across Machines to Design Or Greater Values
- Maintain Proper Amounts of Refrigerant Charge

- Keep Condensers Clean
- Avoid Liquid Refrigerant Carryover Into Compressor
- Operate the Refrigeration Evaporator at the Highest Practical Temperature (Pressure)
- Minimize or Eliminate Air In-Leakage to Refrigeration Machines
- Operate the Minimum Number of Refrigeration Machines for the Load
- Install Refrigeration Optimization Control System
- Optimize Brine System Concentration
- Install Thermal Storage to Shift Load Off-Peak
- Use Absorption Refrigeration Driven by Low Level Heat
- Shift Loads From Chilled Water to Cooling Tower Water When Feasible
- Precool With Cooling Tower Water Before Applying Chilled Water

Cooling Towers

- Run Minimum Number of Pumps
- Throttle Flow in Plant to Get the Design Delta T Across the Tower
- Select Fan Speed for Ambient Conditions
- Install Adjustable Pitch Fan Blades
- Maintain Correct Cycles of Concentration
- Maintain Tower Equipment to Run at Design Conditions

Heating, Ventilating, and Air Conditioning (HVAC)

- Heating, Ventilating, and Air Conditioning (HVAC) Control Systems
- Use Exhaust Air to Heat or Cool Other Areas
- Balance Air Flows to Meet Actual Loads
- Ensure That Exhaust Flow Matches or Balances Conditioned Air Supply
- Ensure That Duct Work is Free of Obstructions
- Ensure That Terminal Diffusers and Ducts are Clean
- Keep Coils Clean
- Keep Air Filters Clean
- Keep Fans Clean
- Control Flow Through Air Washers Where Possible to Adiabatic Operation
- Repair or Replace Air Washer Nozzles That Do Not Atomize Properly
- Trim Impellers on Air Washer Pumps When Oversized or Install Smaller Impeller
- Make Sure Control Valves to Coils Completely Shut Off When Not in Use
- Make Sure Steam Traps on Heating Coils Function
- Make Sure Dampers on Coil or Air Washer Systems Close Completely
- Maximize Supply Air Temperature During Cooling Season and Minimize During Heating Season
- Minimize Control of Humidity Consistent with Personnel and Product Needs

- Minimize or Eliminate Heating and Cooling in Unoccupied Areas
- Install Thermostats on Interior Walls
- Calibrate and Eliminate Poor or Non-performing Controls
- Install DDC Controls to Replace Pneumatic Controls
- Install HVAC Management System
- Utilize Water-Side Cooling Tower Economizer Systems in Winter Where Possible to Replace Chilled Water
- Reduce Preheater Set Point
- Install Adequate Insulation on Chilled Water Systems
- Use Primary-Secondary Circuits and Variable Flow Chilled Water Systems Where Applicable
- Replace Worn or Loose Belts on Fans
- Install Waste Heat Recovery Where Applicable
- Install or Switch to Variable Air Volume Air Distribution System
- Use an Infrared Survey to Locate Heat Loss

Building Envelope

- Install Tight Sealing Doors and Windows to Minimize Infiltration
- Install Hanging Door Seals in High Traffic Areas
- Use Ceiling Fans to Eliminate Stratification of Air in High Ceiling Areas
- Install Adequate Building Insulation
- Install Roof Spray Systems to Minimize Heat Gain
- Utilize Advanced Window Treatments to Minimize Heat Gain
- Where Appropriate, Re-Roof with Light Colored Roofing Materials
- Ventilate Attic Space
- Install Adequate Wall Insulation
- Insulate Partition Walls Between Conditioned and Unconditioned Spaces
- Keep Garage and Warehouse Doors Closed
- Use Self Closing Doors
- Recaulk Doors and Windows and Install Weather-Stripping
- Replace Broken Windows
- Install Vestibules to Prevent Excessive Air Infiltration
- Close Abandoned Stacks

Compressed Air

- kW/100 scfm Should Be <19 for 100 psi and <24 for 160 psi
- Intercool Between Compressor Stages
- Keep Intake Filters Clean
- Cool Air Intake Where Possible
- Monitor Stage Temperatures and Pressures to Detect Problems
- Use Inlet Guide Vanes for Control of Centrifugal Compressor Output

- Control Antisurge Valves with Flow Rather than Pressure
- Keep Antisurge Valves Closed
- Base Load Centrifugals and Carry Swings on Reciprocating Compressors
- Optimize Load Sharing Between Compressors
- Reduce the System Pressure to the Minimum Needed
- Use a Booster Compressor for Small High Pressure Loads
- Use Air Blower Instead of Compressed Air
- Do Not Use Compressed Air for Cleaning or Agitation
- Eliminate Air Trap Leakage
- Repair Air Leaks
- Shut Off Compressed Air to Equipment That Is Down
- Replace "Heatless" Air Dryers with "Heated
- Eliminate Pressure Regulators That Bleed Air
- Monitor Compressed Air Use to Detect Abnormal Changes

Fans

- Use Adjustable Speed Drives
- Reduce Speed with Sheave-Change to Minimize Damper Throttling
- Control Fan Output with Inlet Guide Vane Control to Reduce Throttling Loss
- Keep Fan Belts From Slipping
- Size Ductwork to Give Minimum Static Pressure Loss
- Minimize Duct Leakage

Pumps

- Reduce System Pressure to Minimum Needed by the Users
- Substitute Gravity Flow Where Possible
- Use a Booster Pump for a Small High Pressure Demand
- Connect Heat Exchangers in Series to Reduce Cooling Water Flow
- Operate the Minimum Number of Pumps for the Load
- Install Smaller Impellers to Avoid Throttling Loss
- Maintain Pumps to Produce Design No-Load Discharge Pressure
- Use a Variable Frequency Drive To Control Discharge Pressure

General

- Reuse Water Wherever Possible
- Use Untreated Water Instead of Filtered Water
- Control Water Flow to Coolers and Condensers at Optimum Rate
- Keep All Instrumentation Calibrated
- Measure and Record All Utility Consumption and Analyze Performance and Trends

- Operate the Minimum Amount of Equipment to Satisfy System Loads
- Use DCS and Energy Optimization Systems to Control Efficiently
- Use All Utilities at the Most Economical Temperature and Pressure
- Optimize Piping Systems for Minimum Life Cycle Cost
- Isolate All Unused Energy Consuming Equipment
- Insulate Heated Tanks
- Use Suction Heaters Instead of Heating Entire Tanks
- Repair Hot Water Leaks
- Run Hot Water Heaters at Minimum Temperature Required
- Keep Heat Exchanger Surfaces Clean
- Purchase Only Energy Efficient Equipment
- Use Heat Pumps to Supply Hot Water and Refrigeration
- Operate Internal Combustion (I/C) Engines Only When Necessary

Opportunities for the Employment of Simulation in U.S. Air Force Training Environments: A Workshop Report

DETAILS

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Committee on Opportunities for the Employment of Simulation in U.S. Air Force Training Environments: A Workshop; Air Force Studies Board; Division on Engineering and Physical Sciences; National Research Council

OPPORTUNITIES FOR THE EMPLOYMENT OF SIMULATION IN U.S. AIR FORCE TRAINING ENVIRONMENTS

A WORKSHOP REPORT

Committee on Opportunities for the Employment of Simulation
in U.S. Air Force Training Environments: A Workshop

Air Force Studies Board

Division on Engineering and Physical Sciences

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Bimal Aponso, National Aeronautics and Space Administration,
R. Stephen Berry (NAS), Professor Emeritus, The University of Chicago,
Thomas E. Romesser (NAE), Independent Consultant, and
Jeffery A. Schroeder, Federal Aviation Administration.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views presented at the workshop, nor did they see the final draft of the workshop report before its release. The review of this workshop report was overseen by Robert J. Hermann (NAE), Independent Consultant. Appointed by the NRC, he was responsible for making certain that an independent examination of this workshop report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the committee and the institution.

Contents

Acronyms

ACC	Air Combat Command
AETC	Air Education and Training Command
AFAMS	Air Force Agency for Modeling and Simulation
AFGSC	Air Force Global Strike Command
AFI	Air Force Instruction
AFPD	Air Force Policy Directive
AFRL	Air Force Research Laboratory
AFSB	Air Force Studies Board
AFSOC	Air Force Special Operations Command
AMC	Air Mobility Command
ATD	advanced technology demonstration
C2	command and control
CAF	Combat Air Forces
CCDR	Contractor Critical Design Review
CFL	Core Function Lead
CLS	Contractor Lifecyle Support
COCOM	combatant command
CSAF	Chief of Staff of the Air Force
DMO	distributed mission operations
DoD	Department of Defense
FAA	Federal Aviation Administration
HAF	Headquarters Air Force
HPW	Human Performance Wing
I-LVC	integrated-live, virtual, constructive (LVC)
LPTA	lowest price, technically acceptable
LVC	live, virtual, constructive (training)
MAF	Mobility Air Forces
MAJCOM	major command
MWS	major weapon system

NAE	Naval Aviation Enterprise
NASA	National Aeronautics and Space Administration
NRC	National Research Council
NSA	National Security Agency
OPLAN	operational plan
RGM	rapid global mobility
SECAF	Secretary of the Air Force
TOR	terms of reference
TSRA	Training System Requirement Analysis
TSSC	Technical Support Services Contract
UT-IISC	University of Toledo Interprofessional Immersive Simulation Center
VIR	virtual immersive reality

Overview

CONTEXT FOR THE WORKSHOP

Simulators currently provide an alternative to aircraft when it comes to training requirements, both for the military and for commercial airlines. For the U.S. Air Force, in particular, simulation for training offers a cost-effective way, and in many instances a safer way in comparison with live flying, to replicate real-world missions. Current technical issues related to simulation for training include simulation fidelity and multi-level security, among others, which will need to be addressed in order for the Air Force to take full advantage of this technology.

In this context, the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering requested that the Air Force Studies Board of the National Academies' National Research Council (NRC) undertake a 3-day workshop to (1) examine how simulation is currently used in military services, private industry, and other government agencies, such as the Federal Aviation Administration and NASA; (2) compare alternative uses to current Air Force practices to identify areas where the Air Force can benefit by adopting such practices; (3) examine how current and future technologies will allow the Air Force to gain even more benefit from simulation; and (4) examine how the combination of live training, virtual training in simulators, and constructive/computer generated entities can improve aircrew training. Regarding topics 2 through 4, the areas where the Air Force can benefit will be grouped into two categories: (1) areas that enhance and/or augment the learning process and (2) areas that may be used as a substitute for some training requirements with operational systems.

A committee of experts was appointed by the NRC in October 2014. The workshop was held on November 17-19, 2014, in Dayton, Ohio. Speakers were asked to respond to the following questions:

1. What are you doing now with simulation?
2. What are your current limitations?
3. What would you like to be able to do?
4. What technologies, approaches, and techniques do you think have promise to help make your desires in #3 possible?

The scope of the workshop focused on technologies and practices that could be applicable to high-end aircraft simulations. Thus, representatives of the U.S. Navy were invited to present on the uses of simulation for training by the Naval Aviation Enterprise, while the representatives of the U.S. Army, which is a fairly sophisticated user of simulation, were not present.

RECURRING THEMES ARISING DURING THE WORKSHOP

During the course of the 3-day workshop, common messages, or themes, appeared as a result of various presentations and resulting dialog among the participants. These themes are listed below along with the names of the participants who identified the common message. Details underlying each theme are found in the body of the report. *The report summarizes the views expressed by individual workshop* *participants. While the committee is responsible for the overall quality and accuracy of the report as a record of what transpired at the workshop, the views contained in this section and in the rest of the report are not necessarily those of all workshop participants, the committee, or the National Research Council.*

1. For current and future warfighters to be operationally ready on a continuous basis, realistic training in a simulated environment is critical. For Air Combat Command, in particular, training in the live (L) construct linked to Virtual Constructive (VC) is imperative for mission success. For Air Mobility Command training, VC is critical, but its requirements are somewhat fewer with regard to linking to the L environment. With respect to live, virtual, and constructive training (LVC), Air Force Special Operations Command's requirements are between Air Combat Command and Air Mobility Command (Ray Johns, John Corley) (see Chapter 1).[1]
2. Establishing stated requirements for live, virtual, and constructive training as well as implementing a LVC training strategy, capability, and governance model could greatly benefit the Air Force across its full range of missions. This undertaking will likely mean establishing a durable understanding of LVC training's relative worth compared to other components of readiness (Ray Johns, Donald Fraser) (see Chapter 1).
3. Currently, LVC training efforts are evolving in a largely ad hoc, stovepiped, and somewhat inefficient fashion. This situation suggests Air Force consideration of a different architectural approach that would be world-centric—open, pluggable, and playable—rather than platform- and contractor-proprietary-centric. This world-centric construct would contain common elements and live data, such as weather, terrain, threats, with an array of specific simulation platforms around the periphery drawing information from the common databases as opposed to utilizing their own proprietary database (Pamela Drew, Harry Robinson) (see Chapter 3).
4. There are indications that some elements of the Air Force simulation architecture currently have these world-centric enterprise characteristics, so continued pursuit of an enterprise-level solution to LVC training could be very beneficial (Pamela Drew, Harry Robinson) (see Chapter 3).
5. Advances in technology and increasingly complex user needs have led to LVC training as the primary way to train for some missions (Robert Allardice) (see Chapter 3).
6. Substantial benefits could accrue to the Air Force if it relied on open systems and acquired data rights as the model when procuring new systems. Enforcing compliance to more interoperable, related standards could lead to a "plug and play" environment (Pamela Drew, Michael Zyda) (see Chapter 3).
7. Research into the "science of learning" is indicating that young people, who have considerable computer skills compared to previous generations, learn in very different ways compared to older generations. Future architectures and systems would benefit by taking this knowledge into account (adaptive learning) (Donald Fraser, Steve Detro) (see Chapter 3).

[1] *Simulation* is a method for implementing a model over time. *Live simulations* are simulations involving real people operating real systems. *Virtual simulations* are simulation involving real people operating simulated systems or in simulated environments. *Constructive simulations* are simulations that involve simulated people operating simulated systems. (Real people may simulate the simulation by inputs, but they are not involved in determining the outcome) (see Old Dominion University, Modeling & Simulation Course MSIM 695-JAN 2003, Introduction to Combat Modeling and Simulation, Norfolk, Va.).

1

Air Force Simulation Needs

INTRODUCTION

Simulation for training has long been a central part of U.S. aviation. Pilots were first trained on the famous Link Trainer starting in 1934, when the Army Air Corps bought six Link Trainers to assist in training pilots to fly at night and in bad weather relying only on instruments. The World War II era brought orders for thousands of Link Trainers from the United States and many foreign countries. Although Army Air Forces aviation cadets flew various trainer aircraft, virtually all took blind-flying instruction in a Link Trainer.[1]

Today, commercial airline pilots are trained and certified by the Federal Aviation Administration (FAA) for flight operations almost exclusively on simulators. Advances in computer technologies, particularly virtual reality used for gaming, have provided new opportunities for using simulation to approach reality. Simulation techniques known as live, virtual, and constructive (LVC) have been under study by Air Force researchers since the early 1990s. During a visit by the National Academies' Air Force Studies Board (AFSB) in 2011 to Scott Air Force Base, General Ray Johns, then commander of the U.S. Air Force's Air Mobility Command (AMC), suggested, as one of several study topics, a look at migrating additional aircrew training to simulators in a resource-constrained environment. Later actions by the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering and the AFSB led to National Research Council approval of terms of reference (TOR) for this workshop and subsequent appointment of the members of the Committee on Opportunities for the Employment of Simulation in U.S. Air Force Training Environments: A Workshop (see Box 1-1).[2]

The workshop opened with introductions of the large number of participants and guests, several dozen in all. The committee co-chairs thanked the many attendees and noted that this workshop represented both a challenge and an opportunity to assist the Air Force in moving forward with simulation capabilities that could benefit the service in all aspects of its mission. They also established that the greatest benefit of a workshop like this would be the dialog, discourse, and discussions resulting from the numerous presentations over the next 3 days. During and after the meetings, almost all attendees expressed gratitude to the co-chairs, committee members, and the National Academies for enabling this workshop (e.g., "Thank you. This far exceeded expectations. Good to continue this collaboration." [Maj Gen Post, during day 3]).

The committee's process was to look at what is being done now in the Air Force based on current Air Force requirements, to look at what is being done elsewhere, and to compare these, as well as use discussion and committee expertise to identify the areas that can offer further benefit, including items beyond flight crew training. With a few exceptions, the speakers were asked to organize their talks to present what they are doing now, identify the limitations of what they are doing now, identify what they

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[1] U.S. Air Force, "Link Trainer," Fact Sheet, Posted July 29, 2009, http://www.nationalmuseum.af.mil /factsheets/factsheet.asp?id=3371.

[2] Appendix A provides short biographies of the committee members. The committee reflects extensive expertise in computer science, modeling and simulation, gaming, military operations, and human behavior in stressful environments.

BOX 1-1

Terms of Reference

An ad hoc committee will plan and convene one 3-day public workshop to: (1) examine how simulation is currently used in military services, private industry, and other government agencies, such as the Federal Aviation Administration and NASA; (2) compare alternative uses to current Air Force practices to identify areas where the Air Force can benefit by adopting such practices; (3) examine how current and future technologies will allow the Air Force to gain even more benefit from simulation; and (4) examine how the combination of live training, virtual training in simulators, and constructive/computer generated entities can improve aircrew training. Regarding topics #2-4, the areas where the Air Force can benefit will be grouped into two categories: (1) areas that enhance and/or augment the learning process; and (2) areas that may be used as a substitute for some training requirements with operational systems. The committee will develop the agenda for the workshop, select and invite speakers and discussants and moderate the discussions. The workshop will use a mix of individual presentations, panels, breakout discussions, and question-and-answer sessions to develop an understanding of the relevant issues. Key stakeholders would be identified and invited to participate. One committee-authored workshop report will be prepared in accordance with institutional guidelines.

would like to be able to do, and offer their thoughts on how they can achieve this, particularly in use of technology. The speakers were also asked to frame their presentations in light of needs for simulation expressed by the Air Force using commands.[3] The committee considered all Air Force aircraft types, but fighter aircraft and their missions had the most demanding training requirements and became the main focus of the workshop.

After user needs (requirements) and Air Force supporting activities are addressed in Chapter 1, the remainder of this report is organized around the four numbered items in the TOR, namely, examining how simulation is currently used outside the Air Force (Chapter 2) and how the Air Force might benefit from alternative uses and technologies, especially LVC (Chapter 3). A discussion of (1) areas that enhance and/or augment the learning process and (2) areas that may be used as a substitute for some training requirements with operational systems, as specified in the TOR, is found in Chapter 2 and Chapter 3 as part of the participant dialog. Finally, during the course of the 3-day workshop, common messages, or themes, appeared as a result of various presentations and resulting dialog among the participants. Listed next to each theme are the names of the participants who identified the common message. Details underlying each theme are found in the body of the report. *The report summarizes the views expressed by individual workshop participants. While the committee is responsible for the overall quality and accuracy of the report as a record of what transpired at the workshop, the views contained in the report are not necessarily those of all workshop participants, the committee, or the National Research Council.*

USER NEEDS

During the course of the workshop, three Air Force major commands (MAJCOMs)—AMC, Air Combat Command (ACC), and Air Force Special Operations Command (AFSOC)—presented their needs with respect to LVC training. AMC trains, organizes, and equips the Mobility Air Forces (MAF); ACC does the same for the Combat Air Forces (CAF); and AFSOC's responsibilities for its forces are similar. The abstracts for the MAJCOM presentations are reprinted in Boxes 1-2, 1-3, and 1-4. The leaders of the commands and their staffs, committee members, and many guests spent much time over the 3 days

[3] Appendix B provides a list of workshop speakers and the topics that were addressed during the 3-day workshop.

BOX 1-2

Air Mobility Command

Lt Gen Brooks Bash, Vice Commander

Air Mobility Command is the lead command for rapid global mobility (RGM) and is responsible for guiding the Mobility Air Forces (MAF) community in concept development and force structure. The MAF optimizes the active duty, Air Reserve Component, and Civil Reserve Air Fleet to achieve a cohesive system for RGM effects. RGM, through three core mission areas—Airlift, Air Refueling, and Aeromedical Evacuation, is the key to maintaining global presence and a timely response capability that is the backbone of expeditionary operations, such as supporting strike operations with air refueling or moving forces from the continental United States directly to points of effect.

Maintaining the proficiency of our aircrew is essential to the successful accomplishment of RGM, but sequestration and budget cuts have put flight training time at risk. AMC is looking for more efficient ways to effectively train our crews and align training requirements with the appropriate device. Beginning in 1992, the command began an extensive upgrade of its simulators. All AMC pilot simulators are now the equivalent of FAA Level C (or better), allowing the use of flight simulators for many training events that were previously performed in the aircraft. Currently, an average of 61 percent of MAF pilot flight training requirements is accomplished in a simulated environment. The training is good, but we can make it better.

AMC is upgrading visual systems, improving fidelity, and networking simulators through Distributed Mission Operations (DMO) to capitalize on the efficiencies of live, virtual, constructive (LVC) training. Through DMO, AMC will be able to connect non-collocated receivers, tankers, and Boom Operators to conduct virtual air refueling. By putting a human in the loop, the suspension of disbelief is greatly enhanced; crewmembers are held accountable to entities outside of the box and must work together for successful mission accomplishment. DMO is used by the MAF for daily, persistent training and AMC is looking to expand that capability.

There are several mission sets where simulation is not optimal and aircraft training flights remain essential. Tactical events, such as assault landings, airdrop, and air refueling are not yet fully replicated. Also, as we have already migrated over 60% of our training to simulation, any further migration gives us concern for our ability to gain experience in the mission management aspects of our global mission such as enroute support, aircrew management, Air Traffic Control, C2, and ground support interaction that are crucial for the development of our aircraft commanders. (See second attachment.) Flight training for Loadmasters, Boom Operators, and Aeromedical Evacuation Crewmembers also represent an opportunity as their flight training devices are not as mature as the pilot simulation devices. Indeed, heretofore Loadmasters and Boom Operators gained training as an outcome of required pilot/AC in aircraft flight training, but as we have decreased pilot flight time these crew positions require increased simulator capacity and fidelity to achieve requisite training.

AMC is keenly interested in garnering an expanded awareness of cutting-edge simulation in the aviation industry; ready to capitalize on synergies that will increase the efficiency and effectiveness of aircrew training system.

discussing these needs, their policy and technical implications, and how they could be satisfied. Understanding these needs fully was essential to progress toward identifying how a range of alternative uses of simulation and a variety of simulation technologies could benefit the Air Force.

SPEAKER COMMENTS RELATED TO AIR FORCE NEEDS FOR LIVE, VIRTUAL, CONSTRUCTIVE TRAINING

LVC is an opportunity for the MAF; but a necessity for the CAF.

—Lt Gen Brooks Bash, AMC

Although Lt Gen Bash's focus was more on efficiencies, which could be gained by moving additional flying hours to simulators, he did recognize that some LVC simulation for training could be very helpful to prepare those MAF elements needed for actual combat, such as refueling and some airlift

BOX 1-3

Air Combat Command

Maj Gen James Post III, Vice Commander

Air Combat Command is the primary force provider to America's warfighting commands to support global implementation of national security strategy. ACC operates fighter, bomber, reconnaissance, battle-management and electronic-combat aircraft. It also provides command, control, communications and intelligence systems, and conducts global information operations. In order to adequately prepare warfighters for future operations across the Air, Space, and Cyber domains, the Combat Air Force (CAF) needs the capability to train and test in a highly realistic and contested environment. This environment can best be replicated using a combination of LVC assets. Advancements in digital technology are enabling the Air Force and Joint communities to integrate the LVC environment into a holistic and realistic training environment where future generations of warriors can be trained. Current training in the Virtual-Constructive (VC) environment is well advanced, but the CAF has a great deal of work to do to integrate VC entities into the live training environment.

Training Advantages of Combat Air Forces (CAF) LVC Capability

Live training will remain a critical and irreplaceable part of CAF training to ensure the entire "system" (aircrew, aircraft, maintainers, supply chain, support functions) is prepared for war. Aircraft must be flown against live targets, surged regularly and subsequently "broken," to validate what works and what doesn't work. CAF aircrew needs to train in real-world conditions/limitations. Examples include: wingtip vapor trails that give away a stealth aircraft's position, altitude block and training rule limitations, high-G environments, inoperative radars or radar warning receivers, and real-world radio communication interference/confusion.

Future VC training will be a critical enhancement to Live training. Once integrated into the live environment, VC will enable a robust, complex, and more cost-efficient threat environment than could ever be replicated by live assets alone. High-end adversary threat capabilities will be replicated in a secure VC environment that is then integrated with live adversary threats. Live and virtual aircraft will engage Live, Virtual and Constructive threats over a secured training network without divulging their full combat capabilities. Live blue air will be integrated with VC support assets (service, Joint or Coalition) to practice synchronized operations that are difficult to replicate in the live environment alone. CAF assets will virtually practice OPLAN missions against constructive Integrated Air Defense Systems that accurately replicate realistic Enemy Orders of Battle. The result is training in a realistic domain where simulated versus live training is only a matter of physical location of the cockpit, and the stimuli of the physical environment.

LVC Operational Needs/Requirements

The CAF LVC environment will exist to provide "expert level" training to operational warfighters and provide an integrated readiness training environment in which warfighters solve dynamic mission execution problems. Today, CAF VC utilizes Distributed Mission Operations (DMO) to connect multiple simulators at varying locations throughout the world for daily team training scenarios—from unit-level package-sized tactics, to large scale exercises among Service, Joint and Coalition warfighters. Tomorrow, the CAF must inextricably link the "VC" to the "L."

In addition to high fidelity concurrent simulators, the CAF requires access to suitable training ranges, airspaces, and training assets for realistic aircrew training. Because the military's training requirements reflect changing technologies, capabilities, and global threat estimates, the AF must continuously review its training requirements and fund for required changes that keep pace with warfighter requirements.

missions. Lt Gen Bash was also interested in ways to help him know where to best spend the next dollar on training. Maj Gen James Post III, ACC, was emphatic about the need for linking VC to L, which is necessary to prepare CAF for the high-end fight. "The CAF wants to evolve to a high fidelity training

BOX 1-4

Air Force Special Operations Command

Col Steven Breeze, Chief, Operations Training

Air Force Special Operations is the air component for United States Special Operations Command and the second largest of the five components behind United States Army Special Operations Command. AFSOC is organized into 3 Wings, the 1ST, 24th, and 27th Special Operations Wings. We also have 2 Direct Reporting Groups, the 352nd and 353rd, the Air Force Special Operations Air Warfare Center, one Reserve Command Wing…the 919th SOW, and a single gained Air National Guard Wing with the 193rd SOW. In many cases our Air Commandos and weapon systems are not assigned to just a single mission set. We frequently execute missions that span across multiple core mission areas, almost always in conjunction with our Army, Navy or Marine special operations partners. Those mission sets range from specialized air mobility to precision strike to ISR.

This past summer, the new AFSOC Commander refocused and reviewed the Commands priorities and highlighted the need to improve our training. Out of those extensive reviews, the Command deemed the importance of transforming our training to optimize human performance. Multiple lines of effort were developed to improve our training and refocus standards on excellence. To reach those standards, our goal is to leverage the synthetic environment and state-of-the-art training methods. While all of our simulators are now the equivalent of FAA Level C or better, we do not have simulators collocated with each operational squadron. We are “late to need” programming simulators for our next generation aircraft. While our training systems are not broken, we need to take advantage of the synthetic environment to eliminate the obsolescence of our training systems.

As part of our training transformation, we have systematically reviewed all currency requirements in all of our MWS’s refocusing continuation training to include the simulator. We determined multiple events can be better trained or more safely trained in the simulator. Through this process, we hope to free up aircraft time to increase the amount of joint training we can conduct with our partners and provide more combat power downrange. While we have not reduced the flying hour program, we are setting conditions to absorb a future decline.

Due to our diverse mission sets and the importance we place on crew resource management, there are several areas where simulation is not optimal. While we have not reached the max amount of simulator events capable of being logged in the simulator, we are quickly reaching the limit due to several factors. (1) While the visual systems in our simulators are excellent, they are showing their age (8-10 years) and therefore we cannot replicate the full tactical environment. (2) AFSOC rapidly upgrades aircraft; simulator programs and funding are frequently left behind (late or unfunded). (3) Most of our MWS’s heavily incorporate the “crew concept”; however the simulators and fuselage trainers or back-ends are not linked. (4) The aero models in some of our simulators rely on engineering data and not flight data limiting flight fidelity. (5) Complex databases include six or more layers (imagery, elevation, material, features, light, 3-D models, and radar) and are extremely time consuming and expensive to build manually.

AFSOC is still in the infancy stage taking advantage of Distributive Mission Operations (DMO). Currently, each crewmember participates in one DMO event per semi-annual period. Challenges remain leveraging the capabilities of networked simulation efforts. We have a lack of manpower and simulator capacity to ensure every crew in AFSOC is capable of training in the DMO environment. Also, our threats are not validated or centrally monitored to ensure fidelity. Finally, there is no standardized Multi-layer Security Solution to enable training with 5th generation fighter aircraft.

environment through integration of dynamic L, V, and C.”[4] Maj Gen Post was adamant about not cutting live flying hours: “VC is outpacing L . . . but L is a necessity for the CAF. We need to focus on the ‘dash’ between L-VC so we can connect the VC to L.” Col Nathan Hill, Chief of ACC Flight Operations, then added several comments. Col Hill stated that realistic training is a requirement for the CAF to ensure that

[4] The level of simulation fidelity required for training tasks is a topic that recurred during the workshop. The discussion would often refer to the need to understand the level of simulation fidelity required for training effectiveness. The value in doing this was to avoid the cost and technical risk associated with developing a greater level of fidelity than necessary for training effectiveness for a particular mission. The importance of ensuring correct “muscle memory” for controlling the vehicle through training in addition to higher-level decision making was also emphasized during discussions.

the Air Force is prepared for *all* contingencies across the range of military operations. In addition, Col Hill believed that the desired end state for CAF is full LVC: putting virtual and constructive into live aircraft. He further noted that CAF needs to determine the right balance of live fly and simulation (the equation will likely be changed every 1-3 years) and needs to resolve security concerns as we put more and more onto various networks (an ongoing concern). Finally, Col Hill stated that CAF also needs technology advances to ensure full LVC (e.g., What waveform will live aircraft use? and How will the VC be put into each type of aircraft?). Many participants pointed out that AFSOC's requirements fell between AMC and ACC with respect to LVC.[5]

COMMITTEE COMMENTS RELATED TO AIR FORCE NEEDS FOR LIVE, VIRTUAL, CONSTRUCTIVE TRAINING

Robert Allardice, former vice commander of AMC, noted that complexity and advances in warfare have moved to the point where legacy training platforms are inadequate in producing operationally ready aircrew. Therefore, according to Mr. Allardice, the Air Force must undertake LVC training methods to integrate 5th-generation aircraft [red and blue] into its "simulation" training portfolio because the current construct is inadequate. "Operationalize" LVC and have acquisition programs address that. Recent advances in technology allow for investments in distributed training with a very favorable return on investment (due to cost avoidance). Mr. Allardice submitted that this is the efficiency side of the argument that seems to be the focus of AMC. Advances in simulation must have the following common attributes: concurrent, dynamic, realistic, and degraded operations.

John Corley, former ACC commander and former Air Force vice chief of staff, noted that the Air Force needs both a more effective and efficient approach for the training environment. He went on to say that ACC's demands tend more toward the effectiveness imperative while AMC sees the greatest benefit (while not exclusively) in efficiency, especially given the severity of fiscal constraint. Mr. Corley offered that both commands can benefit from the development of a realistic training domain where simulated versus live training is only a matter of physical location of the entity and the stimuli of the physical environment; an approach that potentially yields this realistic domain is through a properly constructed LVC capability. Finally, he noted that development of the above can include a process to demand compliance with requirements and funds for required changes that will keep pace with warfighter requirements.

Steve Detro, a business development lead for Lockheed Martin Mission Systems and Training, noted that, since 1986, MAF, and AMC specifically, has operated under the policy of using FAA Level C and FAA Level D equivalent flight simulators to train for 100 percent of transport aircrew certification. He went on to say that this policy has generated tremendous savings and continues to do so due to the fidelity of the aircrew produced. Mr. Detro believes that some elements of aircrew experience development have been identified as needing additional focus of training (e.g., airmanship, judgment development, and overall seasoning of aircrew) and would benefit from a higher level of virtual environment fidelity in simulation. LVC could provide more efficiencies and cost savings for high-risk mission training tasks. Finally, Mr. Detro noted that LVC could provide higher-level skill development, such as "edge of the envelope" training for missions like air refueling, air assault, airdrop, etc. Pertaining to CAF, and ACC specifically, Mr. Detro stated that since the development of Distributed Mission Operations (DMO) networked simulators in the early 1990s, ACC has fielded and is using simulation to do team training between disparate air platforms in progressively more complex operational environments—for example, training for multi-ship tactical, joint service operations, coalition exercises,

[5] There were several comments from participants on the importance of LVC in training/mission rehearsal for integrated Strike packages. It was mentioned that individual components of a package could be trained on simulators, but combined packages were trained using actual aircraft, which is expensive and risky. Effective use of LVC to train combined packages for ACC is critical.

and large force exercise work-up (i.e., Virtual Flag and Red Flag). He noted that ACC has moved to using high-fidelity simulation for a larger percentage of its training versus live fly, but does so under the philosophy of using the simulation sortie to complement the quality of the live fly sortie. The ratio of simulation to live fly is different for each aircraft type, due in part to the different levels of fidelity of each simulator. The newest fighter flight simulation technologies are enabling the F-35 pilot training center to move more than 50 percent of flight training sorties out of aircraft live fly into the virtual reality flight simulator. Other fighter training programs are also being enabled, through simulation fidelity improvements, to move a portion of their training sorties to virtual simulation as the fidelity of each aircraft simulator permits. Mr. Detro observed that LVC is an imperative for both 4th- and 5th-generation fighter operations, a must-have to complement current levels of live flight operations. DMO, the predecessor technology to LVC, currently supports approximately 25 percent of the high-end training and tactics training in the Air Force. Mr. Detro believes that sustained funding is required to fully realize the benefits.

AFSOC, Mr. Detro noted, uses distributed (networked) simulation for a very large percentage of its crew training due to high dependence on total crew proficiency in high-tasking mission scenarios; there is 100 percent linking of simulators across AFSOC. Further, Mr. Detro observed, AFSOC requires all crews to use simulation for 30-40 percent of all training. AFSOC, as he noted, has the near-term goal of fielding flight simulators at all operating bases to be utilized for continuation training and continued mastery of high-fidelity aircraft equipment (e.g., night-vision goggles, electronic warfare, and terrain following radar, weapons, sensors, communications, and navigation systems).

Ray Johns, former AMC commander, noted that the strategic environment has changed—we are not at war, so there is no choice but to put red missions in some kind of virtual environment. Harry Robinson, SimLEARN National Program Manager at the Veterans Health Administration, offered that the demands of 5th-generation aircraft do not afford a full spectrum of training for aircrew in a live simulation domain. Mr. Robinson went on to say that use of simulation is critical to ensuring that warfighters are ready on day 1 of combat operations; there are little resources, time, or tolerance to support learning during battle. Mr. Robinson added that there are significant differences between training for currency (based on periodicity) and proficiency (based on competency); just because a pilot drops a bomb once every 3 months, it does not mean that pilot can hit the target. Determining the amount of funding for training based on periodicity is a much easier problem to solve than proficiency. Mr. Robinson submitted that some training is accomplished during actual mission performance (e.g., combat missions, search and rescue, command and control). This training addresses both competency and currency.

Michael Zyda, director of the Game Pike Laboratory at the University of Southern California, believes that the Air Force cannot turn on the secret equipment in training without giving away the secrets. He noted that network security causes training problems, mostly because multiple networks are connected, and he said that the intranets are fine with respect to security. He also indicated that National Security Agency (NSA)-certified multilevel security is needed. Mr. Zyda noted that there are hard-coded requirements in the contracts; consequently, emerging behaviors are not modeled. How to make the environment more dynamic is an issue, in his opinion. Reliability is so high in planes today that they only see systems failures in the simulators. Mr. Zyda submitted that there appear to be assumptions that there will always be a "man-in-the-loop"; he believes the future is clearly autonomous systems. Finally, Mr. Zyda offered that AFSOC wants synthetic environments and state-of-the-art training devices; AFSOC has special mission equipment that must be in the simulator. For continuation training, the desire is to do all of it in the simulator. He noted that AFSOC would also like higher-end events in the simulator, but they are not there yet. The dialog about user needs led to the first key theme of the workshop.

> **Theme 1.** For current and future warfighters to be operationally ready on a continuous basis, realistic training in a simulated environment is critical. For Air Combat Command, in particular, training in the "live" (L) construct linked to "virtual constructive" (VC) is imperative for mission success. For Air Mobility Command training, VC is critical, but its requirements are somewhat

fewer with regard to linking to the L environment. With respect to LVC training, Air Force Special Operations Command's requirements are between Air Combat Command and Air Mobility Command (Ray Johns, John Corley).

Further exposition of user needs was offered by Steve Detro:

- For AMC: (1) additional simulation technologies to expand the number and realism of real world experiences for aircrew (i.e., air traffic control congestive environments, mission management, crew resource management, crew fatigue); (2) training technologies that accommodate the different learning styles of today's pilots; (3) methods to objectively measure aircrew competency (note: mission essential competencies and pilot evaluation techniques that were developed at the Warfighter Readiness Research Division of the 711 Human Performance Wing, Human Effectiveness Directorate, Air Force Research Laboratory [711 HPW/RHA] by Dr. Wink Bennett); (4) use of the "science of learning" to optimize the training delivery methods and more efficiently utilize the full range of fidelity levels provided by a family of simulators; and (5) affordability.
- For ACC: (1) a more efficient way to develop, integrate, and deliver a persistent, cost-effective, LVC network across multilevel security simulators; (2) concurrent simulators that more accurately replicate the most current aircraft capabilities; (3) higher-fidelity simulators that accurately replicate aircraft systems, engines, avionics, aerodynamics, weapons systems, sensors, environments, threats, and communication systems; (4) flexibility in the simulation that enables the accurate modeling of combat conditions, to accurately simulate the unpredictable nature of operations in the environment of contested and degraded operations; (5) more efficient process for cross-domain network security; and (6) validated threat systems that are physics-based and exhibit intelligent behaviors.
- For AFSOC: (1) accurate validation of the optimal ratio and training balance of simulation "virtual" training versus aircraft-based "live" training; (2) upgrade of AFSOC's legacy simulators to fix limitations (i.e., fidelity of visual environments for night-vison goggles at low-level operations, aero models, concurrency, faster scenario development, and physics-based electronic warfare models); (3) simulation of ramp operations to reduce the number of vehicle-aircraft collisions; and (4) better implementation of the ability to generate simulation scenarios that present situations or events that surprise aircrew during simulation evaluations.

Relatedly, John Corley offered that chasing physical fidelity may be a fool's errand. "Sufficient fidelity" could be delivered through "perception of reality." In turn, Mr. Corley submitted, we could achieve desired and measurable behavior. Steve Detro suggested that the Air Force continue to analyze potential benefits of virtual reality and gather measurable data to substantiate that the higher the fidelity, the higher the benefit. Finally, Harry Robinson noted that realistic simulation and credible simulation are not interchangeable terms. Realistic simulation is the measurement of fidelity and resolution. Credible simulation is the measure of trust in the simulation for providing an immersive training environment that supports the suspension of disbelief.

AIR FORCE PROGRAMS TO SUPPORT USER NEEDS

Representatives from Air Force Headquarters described broad, top-level guidance regarding simulation that reaches all major commands and nearly all core functions of the Air Force (see the abstract in Box 1-5). Below is a relevant extract from one piece of this guidance. Figure 1-1 depicts a notional end-state for LVC-Operational Training (LVC-OT).

> This LVC-OT Flight Plan highlights the areas and item that need particular attention to advance the LVC-OT program and realize its full potential. The specified enabling processes address a governance structure, processes, and infrastructure—all essential to furthering LVC-OT

BOX 1-5

Headquarters Air Force and Air Force Agency for Modeling and Simulation

Brig Gen Eric Overturf, Mobilization Assistant to the Director of Operations, Deputy Chief of Staff for Operations, Plans and Requirements

The Air Force Agency for Modeling and Simulation (AFAMS) through the Headquarters Air Force A3 is the lead agent for centralized management of Air Force cross-functional and shared live, virtual, and constructive (LVC) foundational capabilities and resources supporting Air Force Service Core Functions. The AFAMS mission is to provide seamless integration of cross-functional LVC environments for operational training that allow warfighters to maximize performance and decision making. AFAMS serves as the HAF lead for Air Force LVC foundations and integration with the Department of Defense, Service Components, other government agencies, international partners, academia, and industry. This mission provides the necessary development and implementation of standards for common access and interoperability within the LVC domain for efficient and secure global operations (AFMD56 14 JANUARY 2014).

This summer, the Secretary of the Air Force and the Chief of Staff of the Air Force unveiled the Air Force's 30-year strategic vision and introduced the concept of "strategic agility" and stated, "One of the more promising paths to agility in operational training and readiness is in the area of Live-Virtual-Constructive training." The Air Force is in a period of training transition due to available emerging and advanced technologies, fiscal constraints, and inability to train to the actual capabilities of our latest weapons systems highlighting the need to transition from the historical focus on live training to achieve warfighter readiness. There will be challenges at the forefront of this transition, but these challenges are not insurmountable. These challenges do merit closer collaboration with our sister services and our industry partners. Air Force (and national) readiness increasingly depends on the ability to harness and manage complex training systems and systems of systems. To summarize, "Readiness through LVC" is based on Strategic Guidance, OPLANs, and CCDR requirements/demands, utilizing the capability and capacity of manpower and resources on a timeline that is balanced by "fight tonight versus modernize for tomorrow."

The programs encompassed within and touched by the LVC capability are numerous; they reside in every MAJCOM and nearly all 13 Air Force Core Functions. This is an important point because the MAJCOMs remain the key force providers who organize, train, and equip; Headquarters Air Force provides the overarching and broad strategic guidance ensuring standards and standards development are a foundation to the future of LVC. Headquarters Air Force A3 wears two hats in the planning/programming world: (1) as the lead and direct input source for LVC Foundational requirements and (2) as the programming advocate for operational training to help shepherd and support the MAJCOMs/CFLs issues through the Air Force Corporate Structure. Headquarters Air Force conducts support/advocacy/engagement in accordance with the SECAF/CSAF LVC Flight Plan signed in February 2013 and are working to codify this process in enduring and binding documents such as AFPD 16-10 Modeling and Simulation, AFI 11-202V1 Aircrew Training, 11-2MDS-V1 MDS Training, AFI 36-2251 Management of Air Force Training Systems, and AF Mission Directive 56 Air Force Agency for Modeling and Simulation, to name just a few. Our top priorities are to (1) support and advocate on behalf of the force and codify LVC standards and (2) provide support and Authorizing Official duties for Cybersecurity and Authority to Operate/Connect for LVC-related training systems.

The Air Staff under HAF/A3, Gen Field, developed these four enduring lines of effort to capture the LVC strategic focus: (1) LVC Foundations—develop policy and guidance that enable effective, efficient, training, test, and analyses in a secure LVC domain; (2) Aircrew Training Devices (Sims)—develop Air Force strategy and policies that align with COCOM requirements and Joint policy that provide affordable ATDs with timely concurrency, sufficient fidelity, and appropriate connectivity; (3) Distributed Training—develop the appropriate Air Force strategy and policies to enable effective, secure, distributed training in Air Force and Joint synthetic training environments; and (4) Full LVC—develop an Air Force strategy that aligns with Joint programs to integrate live aircraft, space, and cyber systems with virtual battle spaces.

Ultimately, the goal is a fully integrated operational training continuum, where "live" aircraft on a range fully integrate with "virtual" participants in simulators and "constructive" entities representing Red/Blue Air, Threats, Ground Forces, and Targets, all supported through readiness/distributed training centers and range control complexes for full spectrum combat ops training.

NOTE: The Air Force provided the following document to the workshop participants to illustrate current initiatives related to LVC training: "Bullet Background Paper on Air Force Live, Virtual, Constructive Vision and Strategy," Col Crites/AFAFMS/CC/970-5701/srfs/18 Nov 2014; Air Force LVC-OT Standards Profile.

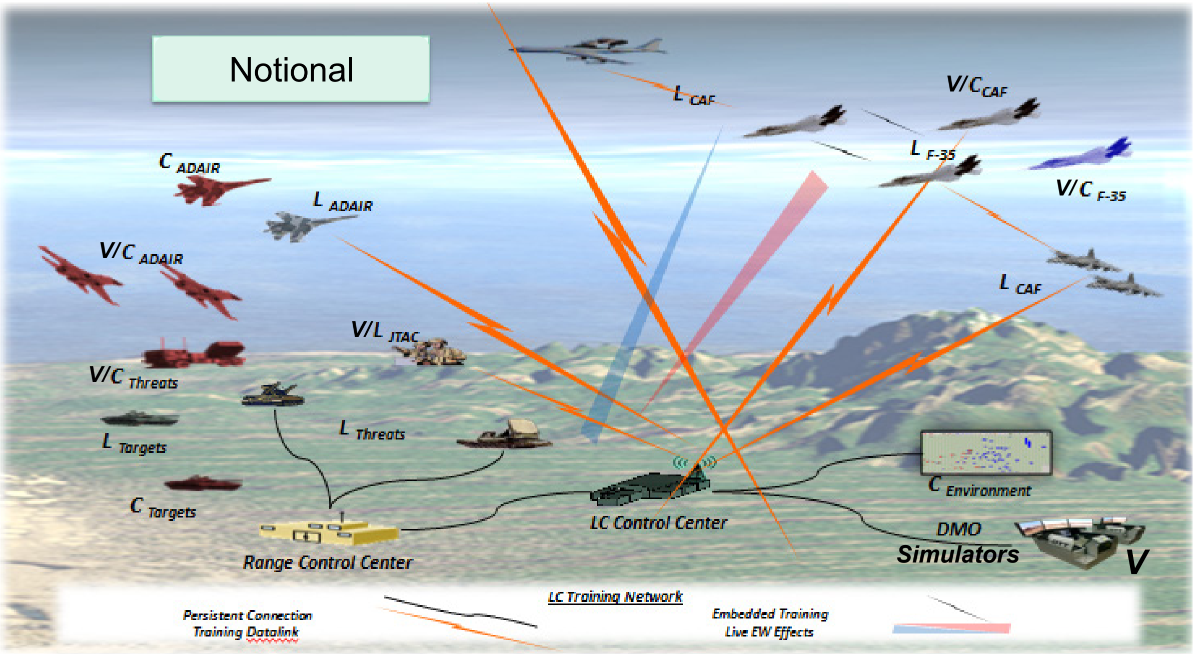

FIGURE 1-1 Notional end state for live, virtual, constructive-operational training (LVC-OT). NOTE: The "nirvana" end state for Air Force simulation is where all Air Force weapon platforms are linked together to enable realistic, distributed mission operations in a live, virtual, constructive environment. SOURCE: Brig Gen Eric Overturf, Mobilization Assistant to the Director of Operations, Deputy Chief of Staff for Operations, Plans and Requirements, Headquarters U.S. Air Force. SAF/PA Approved for Public Release 2014-0569.

> capabilities. Four key focus areas (LVC foundations, weapon system simulators, distributed training, and full LVC) are introduced and will lend permanency and stability to current LVC activity. Air Force-level requirements and investment strategies are also established to ensure operational and technical priorities are addressed, funded, sustained, and are in-line with operator readiness requirements. Finally, the LVC-OT Flight Plan identifies roles and responsibilities at all levels within the Air Force and provides a time horizon for specified actions.[6]

Several committee members reacted to the issues of attention to LVC at top levels of the Air Force and broad Air Force application of simulation technologies. First, John Corley noted that consensus must be reached on the current vision (modified at appropriate frequency) for LVC and that there must be an advocate, with both responsibility and authority, to deliver vision, strategy, and strategic plan for LVC. Mr. Corley submitted that Air Force communities (i.e., MAJCOMs) have arrived at the limits of live training. Further, he believes that separate and distinct virtual (simulation) or constructive approaches, when applied in an additive fashion, will not meet the knowledge transfer threshold today, much less the future. The appropriate integration of L, V, and C can achieve the full spectrum of needed training while also benefiting those requiring training across the full range of military operations. Mr. Corley offered that simulations growth through a prudent, commonly accepted LVC approach can provide increased learning benefit for the full complement of mission capabilities and developmental activities.

On a related topic, Ray Johns, committee co-chair, stated, "The Air Force needs an overall LVC strategy. The Air Force needs to state the LVC requirements, which will drive an acquisition strategy, which will drive a program." Committee member Richard Reynolds, former vice commander Air Force Materiel Command, noted that establishing a durable understanding of LVC's relative worth compared to

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[6] U.S. Air Force, *United States Air Force Live Virtual Constructive Operational Training Flight Plan,* February 22, Washington, D.C.: Headquarters U.S. Air Force, 2013.

other components of readiness is necessary. LVC is ultimately going to have to compete against other Air Force programs and priorities. Of course, he offered, work will be needed to define "durable" and "relative worth," and, when done, one result will be discarding things that are not necessary. Strategic communications (aka "marketing") will be important. In the eyes of Harry Robinson, committee member, there would appear to be many more applications for employment of simulation in Air Force training environments than has been addressed. With major emphasis on ACC, AMC, and AFSOC, Mr. Robinson thinks there would be value in opening the aperture for a bigger simulation umbrella to include Air Education and Training Command, Air Force Global Strike Command, Information Dominance, Air Force Space Command, and Air Force Research Laboratory. Mr. Robinson believes there is also a need to have simulation solutions that are driven to support inter-service training events. Committee member Michael Zyda offered that, clearly, the Air Force could use a chief architect and standards for its LVC systems. That is one of the biggest messages. The dialog about top-level guidance led to a second key theme of the workshop.

> **Theme 2.** Establishing stated requirements for live, virtual, and constructive training as well as implementing a live, virtual, constructive training strategy and governance model could greatly benefit the Air Force across its full range of missions. This undertaking will likely mean establishing a durable understanding of live, virtual, and constructive training's relative worth compared to other components of readiness (Ray Johns, Donald Fraser).

Speakers from the Air Force Life Cycle Management Center and the Air Force Research Laboratory described various research and development, acquisition, and sustainment efforts under way to satisfy the top-level guidance and meet the user needs (Boxes 1-6 and 1-7). This part of the workshop delved into more technical detail. Illustrative comments from committee members appear below; some of these comments feed back to the needs addressed earlier, while others are precursors to more broad-based comments, which arose later in connection with discussions of a different approach for implementing a simulation architecture.

Committee member Robert Allardice noted that the Air Force simulation roadmap appears to be very immature (standards, disciplined investment, adaptability, distribution architecture, etc.) and that there seems to be a role for a "simulation" integrator across all platforms. Committee member John-Paul Clarke, associate professor in the Daniel Guggenheim School of Aerospace Engineering at the Georgia Institute of Technology, submitted that the flexibility and fidelity that is desired by the Air Force stakeholders will require a modular simulation framework where all possible (or at least a large number of) combinations of L, V, and C elements can be put together so that individual units can schedule and control the conduct of complex or high-end training. He believes that such a framework will be expensive; thus, the development plans must include a transition plan that is dynamic and can respond to variances in funding to ensure that new capabilities are provided at the end of any fiscal year. Dr. Clarke believes time synchronization will be a challenge and that predictive cueing is an obvious approach to mitigating the effects of latency. Another possible approach, according to Dr. Clarke, could be to mix event-based and time-based simulation such that event messages are sent in parallel to real-time data exchange to ensure that specific things that must happen at a certain time actually do occur at that time. Also, for agent-based simulation, Dr. Clarke believes that one needs to know which agents are involved, how much they are involved, and, especially for VC into L, who is the training target.

Committee member Pamela Drew, executive vice president and president of Information Systems, Exelis, Inc., provided that LVC technology has advanced over the past 15 years or so in industry and laboratories, and solutions to some of the Air Force gaps do exist (e.g., the need for virtual reality in heads-up displays). However, she noted, there are major gaps in terms of operational needs of the Air Force to apply LVC to their mission set in a practical way. These gaps include ways to address safety, security (particularly in external DMO networks and coalition efforts), and standards for weapon system interface modifications to achieve interoperability and integration. (Note: this can be referred to as "Operational LVC.") Ray Johns submitted that the Air Force has a need for mission-oriented investments

BOX 1-6

Air Force Life Cycle Management Center Simulators Division

Col Daniel Marticello, Chief

The Simulators Division is the U.S. Air Force's primary agent for the acquisition, sustainment, and modification of aircraft training systems, including flight simulators, maintenance training devices, simulator interoperability solutions, and related services. The division is a component of the Air Force Program Executive Office Agile Combat Support Directorate, located within the Air Force Life Cycle Management Center, Air Force Materiel Command, Wright-Patterson AFB, Ohio.

The Simulators Division consists of over 400 acquisition professionals representing the program management, engineering, contracting, finance, and logistics management fields working together to provide solutions to a variety of ACC, AMC, AETC, AFSOC, AFGSC, and foreign military training requirements. We are responsible for over 40 aircrew and maintenance training system programs, executing a more than $1 billion annual budget for systems and services at over 100 locations worldwide. In addition to aircraft simulators and training devices, the division manages the Air Combat and Air Mobility Distributed Mission Operations programs, providing the Air Force's only live, virtual, and constructive (LVC) operational training capability.

The leadership of the Simulators Division is focused on seizing opportunities for innovation within the sphere of training, cost-capability trades, and the state of the simulator industry. A large modification to an existing weapon system or the procurement of a new one to perform an existing mission presents an opportunity to scrub how training is provided. Simulator technology has moved significantly forward over the past decade in the areas of fidelity and networking. Training system methodologies have also matured, especially within the private sector, allowing more training objectives to be "off-loaded" and "downloaded" to simulators and accomplished at a lower cost.

The way forward to ensure that we capture these advances in capability and the promise of lower cost is to first conduct a Training System Requirements Analysis (TSRA). This study effort looks to capture all of the required learning objectives, throughput and availability expectations, and technology available. This information can then be used to support industry proposals on how best to deliver the training and what simulator devices are proposed. This approach allows industry to bring innovative solutions to the table in a best-value, trade-off type of competition. Subsequent CLS/TSSC and modifications are delivered via a separately competed contract vehicle following an initial period of interim contractor support provided under the production contract. TSRAs are also essential in understanding where best to apply the power of the LVC construct. An informed view of what objectives require interaction between the L, V, and C aspects of training will allow the Air Force to best apply limited resources.

Balanced cost-capability trade-offs are essential in this time of shrinking budgets. The Simulators Division is committed to utilizing data from existing contracts to close the feedback loop. Capability provided should match the level of capability needed. Reductions in capability should also be considered if a large savings can be obtained without a negative effect on mission accomplishment.

The simulator industry is experiencing a change in environment. Small Business Set-Asides, LPTA source selections for sustainment, and data rights are all areas that have unintended consequences. It is wise to understand the macro-level implications of decisions made at the individual program level.

to support LVC to prioritize where to put the next dollar (see Figure 1-2). The most challenging mission and biggest gap, according to Mr. Johns, is the mission set of training for the peer/near-peer adversary against 5th-generation systems; this is the integrated capability for which the Air Force must have LVC at a level that does not exist today. Without it, in the opinion of Dr. Drew, it is very likely that the Air Force is not going to be adequately trained for all threats. The MAF mission can benefit from such an LVC capability in terms of mission support, but will also reap higher dividends in efficiency (i.e., savings). In addition, Dr. Drew noted that the MAF (by repurposing the efficiency savings) could train for higher-end capability. The core architecture for such LVC exists, she believes, and it needs to be assessed for scale, robustness, and extensibility, among other things, as well as for what is needed to implement the Operational LVC to support the 5th-generation scenario. Lastly, Dr. Drew believes if that can be solved, the rest of the missions will be a subset of the solution.

BOX 1-7

Air Force Research Laboratory

Winston Bennett, Division Technical Advisor for Training and Assessment Research, 711 Human Performance Wing

The Warfighter Readiness Research Division of the 711 Human Performance Wing, Human Effectiveness Directorate, Air Force Research Laboratory (711 HPW/RHA), is the Air Force's premier research and development organization for education and training. The division pioneered the development of Distributed Mission Operations in Collaboration with Air Combat Command. The division has also led the development of methods and tools to persistently gather and track mission performance and proficiency data for the development of more targeted approaches to training. The division and its operational, industry, and academic partners continue advancing the state of the art in learning, performance, and modeling theory and practice. The division also continues to pioneer and advance distributed mission training and live, virtual, and constructive training methods and capabilities and our research continues to drive the Air Force's vision and investment for the future of operational readiness training.

Recent Highlights and Advances

The division is growing our involvement in the Human Systems Community of Interest, promoting stronger collaborations with industry and our international collaborators. Further, the division is creating and transitioning proof of concept developments in learning management and performance measurement technologies, game-based applications for maintenance training, unmanned aircraft operations, low-cost 5th-generation tactical training, and agent development for autonomous operations, man-machine teaming, and increasing the realism and credibility of live, virtual, and constructive training environments. Our groundbreaking research in cognitive models and agents continues to define and push the science and practice state-of-the-art with successes like the synthetic teammate validation work, the growing collaboration with the American Heart Association and the Defense Health community, and prototypic agent-enhanced sensing for autonomous operations. The team is making great progress in integrating agents into operational training simulations to both improve the credibility of the environments for training and also to increase their efficiency by reducing the need for human "white force" support through the use of model-based agents and avatars. Finally, we completed our first distributed live, virtual, and constructive Close Air Support training trial with the U.S. Army, and we also completed our first and very successful demonstrations of medical operations training research technologies for critical care air transport teams, emergency responders, and pararescue personnel.

Looking to the Future

Of course, we are also mindful of the need to continue to look to the future and to ensure that the developments we make today are meeting the operational demand signals we have and are foundational to continued advancements down the road. Our current work has a strong emphasis on helping the Air Force realize its vision for realistic and secure live, virtual, and constructive training, but it is also a pointer to our future directions for personalized, performance-based learning and readiness assessment. In the future, our education and training systems must be agile and responsive to create the resilient Air Force workforce for the future fight that is more responsive, realistic, and pervasive than we know our adversaries will be.

In the eyes of Harry Robinson, current and planned capabilities can meet Air Force needs. The big challenge is drawing lines to define acceptable capability levels at a given point of time that will be acceptable to meet Air Force training requirements. Otherwise, Mr. Robinson notes, it becomes a "death spiral" development. By definition, Mr. Robinson noted, all models are wrong or incomplete; however, some models are useful. He believes it is unreasonable to recreate the actual world in a virtual environment; the challenge is met by acquisition of sufficient simulation to meet the requirement, not more. Mr. Robinson thinks that simulation-based training can and should be focused on specific flight regimes. Analysis of mission conduct, he said, should include disaggregation of specific tasks—from

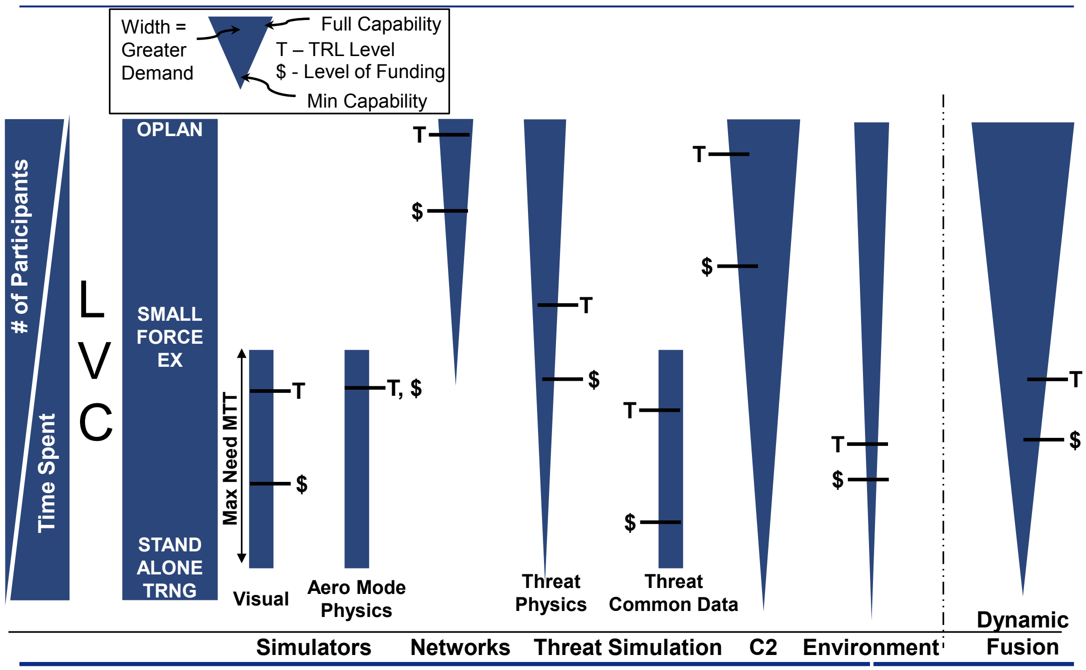

FIGURE 1-2 Notional simulation assessment methodology. SOURCE: Ray Johns.

mission brief to man-up, launch, conduct, land, and debrief. In addition to end-to-end training, Mr. Robinson said, task-trainers and games present unique opportunities to maximize training resulting in proficiency improvements. Finally, he noted that cyber and security demands require attention in modeling and simulation for the training domain; these cannot be effectively backward-engineered into the solution.

2

How Simulation is Currently Used by Military, Industry, and Government Agencies

OTHER MILITARY USERS

Maynard Zettler, director of research and engineering, Naval Air Warfare Center Training Systems Division, discussed the Navy's simulation activities (Box 2-1). The important focus was on the Naval Aviation Enterprise's (NAE's) initiative to improve training by optimizing live, virtual, and constructive (LVC) simulation to match the Navy's recent thrust of integrating its warfighting capability across mission areas, platforms, sensors, weapons, and kill chains. Mr. Zettler explained that this new integration concept differs from prior "stovepipe" approaches and has support at top levels of the Navy.

INDUSTRY USERS

Speakers from Lockheed Martin and Boeing presented simulation approaches of the large U.S. aircraft manufacturing industry (Boxes 2-2 and 2-3), whereas CAE, Inc., and FlightSafety International presented approaches of smaller but important simulation entities (Boxes 2-4 and 2-5). These presentations covered a range of simulation activities and concepts, including small, head-mounted visual displays; large and complex simulators; pilot training and training for other skills (e.g., maintenance); architectures having "the world" embedded in an individual platform simulator; and "world-centric" architecture from which individual platform simulators extract common data (e.g., weather, terrain).

GOVERNMENT AGENCIES AND OTHER USERS

Jeffery Schroeder, chief scientific and technical advisor, Federal Aviation Administration (FAA), and Bimal Aponso, chief, Aerospace Simulation Research and Development Branch, National Aeronautics and Space Administration (NASA), presented the simulation approaches from these two large agencies of the U.S. government (Boxes 2-6 and 2-7). Mr. Aponso offered that NASA has a substantial aeronautical simulation capability, which can be made available at cost to outside users (e.g., for simulating aspects of national airspace) but is no longer central to the agency's main mission of space. Mr. Aponso noted the difficulty of retaining relevant skills in aeronautical simulation activities at NASA. Finally, he discussed NASA's development and testing of an LVC architecture for researching integration of unmanned aerial systems into the National Airspace System (NAS). As part of this development, NASA is characterizing latencies throughout the LVC using a realistic NAS air-traffic simulation and is developing improved communication protocols to integrate the L with the VC components. Mr. Aponso offered that this work may be useful to the Department of Defense (DoD).

In contrast, Dr. Schroeder explained that the FAA oversees U.S. civil aviation in which pilot training and checking is done predominantly in simulators, and the agency sees no reason to change this paradigm. Dr. Schroeder's video clip at the workshop showing pilot reactions to the introduction of highly unusual events into simulator routines was of special interest.

BOX 2-1

Naval Aviation Enterprise

Maynard E. Zettler, Director–Research & Engineering, NAWCTSD

The Naval Aviation Enterprise (NAE) is undertaking multiple initiatives to improve training optimization and proficiency. Central to many of those initiatives is the utilization and integration of Live/Virtual/Constructive (LVC) simulation to augment and improve training. The "LVC in Naval Aviation Training" presentation will focus on the NAE's operational context and integration across the LVC domains. The ultimate objective is the optimized use of LVC to improve the NAE's Integrated Warfighting Capability across mission areas, platforms, sensors, weapons and kill chains. The presentation will address the LVC Training Requirements Path and the process for defining not only what needs to be trained but also utilizing the science of learning to understand the most effective methods to accomplish the training and sustain the requisite skills. The challenge is not just within a given platform but across platforms and the complementing entities in the kill chain(s). Representative examples of current initiatives will be provided, coupled with a discussion on investment gaps and barriers to success.

BOX 2-2

Lockheed Martin Mission Systems and Training

Rick Boggs, Senior Fellow

Lockheed Martin and the U.S. Air Force ATARS II program have engaged in successful human performance engineering. For the past four years there has been an activity centered around Training Transformation that has made some very good progress. With the entry of the F35 into the fleet comes a challenge of Live Virtual Constructive environments. Lockheed Martin is working on a LVC environment known as ACES to address the inclusion of 5th-generation aircraft. Today's training requirements require a 360 degree visual display that is expensive to purchase and operate. I think the requirement should be adjusted to allow for the new man-wearable technologies. These new technologies save considerable expenses and do not reduce the quality of the visual display to the air crew.

The last speakers of the workshop were from the University of Toledo and the State University of New York at Binghamton, and they presented simulation approaches in the medical field (Box 2-8) and an academic modeling approach (Box 2-9), respectively.

FOLLOW-ON REMARKS

After commenting at the meeting, Sharon Conwell, senior research psychologist, Warfighter Training Systems and Performance Assessment Branch (RHAS), Air Force Research Laboratory, made a special effort to provide written comments regarding the medical presentation.

> Thank-you for allowing AFRL/RHAS (Wink Bennett and I) to attend the LVC AFSB study discussion. I found the meeting most informative. You requested that I provide a sentence or two for your study regarding my comment about the 88th Med Group at WPAFB (Wright-Patterson Air Force Base). According to cost research done by Mr. Jacob Arnst at the 88 MDSS/SGSRM and reported by Col Penelope Gorsuch, Deputy Commander of the 88th Medical Group (88MDG/CD), when comparing the 88th medical group to a comparable private sector medical facility, the medical group loses 38 cents on every dollar. Some portion of the 38 cents is more than likely related to training/readiness costs. Every hospital has significant training costs, but military treatment facilities have additional readiness training costs above those of a private sector hospital. The researchers at

BOX 2-3

The Boeing Company

Steve Monson, Chief Architect, Technical Fellow-Simulation and Training

We are in most certainly in a "do more for less" environment, with a need to provide more effective training for reduced costs. Leveraging innovations in commercial technologies and other industry investments like Integrated—Live Virtual Constructive (I-LVC) simulation require a partnership with the Air Force to maximize utility and benefits. Industry is well equipped to research, develop, and tailor technologies for training, and the Air Force is equipped to evaluate and transition these technologies to acquisition programs.

Leveraging Commercial Technologies

Low-cost commercial immersive visualization technologies such as Oculus may not be ready today; however, the commercial sector is working to solve many of the issues of importance to training such as resolution, field of view, and tracking latency. Research is needed to determine the qualities required for particular uses of low-cost, commercial virtual-reality technologies in training. It is recommended this research be performed in parallel with commercial technology development.

Commercial gaming technologies provide an engaging entertainment environment, rewarding the player for demonstrated competencies—many of which are learned within the game. To benefit from learning afforded by approaches used in gaming, research is needed to identify training tasks most appropriate to utilize game technologies to impart transferrable skills.

Performance Assessment

A wealth of performance data can be captured—physiology data, trainee input data, system performance, outcomes, etc. This data can be analyzed against various performance metrics and utilized as an instructor aid or for instructorless training across multiple ranges of device fidelities to provide feedback on performance or adapt the learning to the student.

Integrated—Live Virtual Constructive

The vision for I-LVC includes the entire kill chain, including C2 and national assets. Both live red and blue assets can be supplemented with virtual and/or constructive participants. All participants appropriately sense and communicate with other participants seamlessly across the L-VC boundary, with the ability to launch air and ground constructive weapons with real-time scoring and kill removal. Instructors have the ability to assume the role of constructive threats to be able to introduce the human element when required. A constructive environment server provides a robust environment, and ground-based tools provide the common operating picture and debriefing capability.

Boeing's foundational integrated LVC research began in 2007 with a live F-15E, a virtual F-15E, and constructive red air in a blue verses red engagement. Progressive development and demonstrations added multiple capabilities for both air-to-air and air-to-ground on the F-15E and expanded to the F/A-18E/F. As a result, industry is ready to deliver I-LVC solutions today. It is recommended the Air Force aggressively pursue an acquisition program to realize demonstrated benefits. Research is needed to determine modifications to live training to realize the maximum benefit from I-LVC, along with targeted developments of credible constructive opposing force and sensor models for certain training tasks.

AFRL/RHAS believe that distributed LVC training can bring down those training costs and improve training effectiveness just as LVC distributed mission operations training has brought down training costs and improved training effectiveness in the aviation community.

BOX 2-4

CAE, Inc.

David Graham, Senior Technical Fellow

CAE, Inc., is a publicly held, independent, medium-sized company with products and services focused on the creation of domain expertise using modeling and simulation. Our business is roughly half military and half "civil," and our business is also roughly half supplying products and half providing services. CAE is honored to have the opportunity to provide our industry perspective on promising new approaches to employment of simulation in the U.S. Air Force Training Environment.

The CAE presenter will briefly review CAE's current products and services in use by the Air Force and other end users and respond to the questions about what we are doing now and what the shortfalls of current simulation industry offerings and technology are.

CAE's view of what we would like to be doing and what it will take to achieve our ambitions will be collected in two broad categories: "not-so-thin" simulation clients and "thin" simulation clients.

"Not-so-thin" is one way to describe high-performance, full-flight simulators that make up a very large part of CAE's product and service offerings to both civil and military customers. Promising new approaches will focus primarily on increasing the capability to interoperate federations of heterogeneous simulators to improve the capability to use simulators for mission sets that AMC accurately describes as "not optimal" in their presentation abstract. The CAE presenter will explore the role of open, consensus-based standards to help achieve the promise that rapidly advancing technology can potentially deliver.

CAE believes there is a very promising future in the use of simulation viewed through "thin" clients: zero-deployment web-browsers on a wide variety of hardware and software platforms. New learning sequences that expose training audiences to simulation at various levels of detail and complexity are becoming possible and offer the promise of low-cost, low-risk, rapid expansion and connectivity of elements of mission management components to distributed mission training and rehearsal events. In addition, the capability to "bring the high-performance simulation software to the desktop or mobile device" offers the promise of new, dynamic, highly engaging learning sequences in what we have traditionally considered "ground school."

The presentation will conclude with a discussion of collaboration between U.S. Special Operations Command and the Joint Staff / J7 in the JLVC 2020. A brief examination and demonstration of the J7 Cloud Based Terrain Generation Service will serve to integrate the points previously discussed and support specific recommendations by the CAE presenter.

BOX 2-5
FlightSafety International

Nidal Sammur, Director of Engineering

FlightSafety International has long believed the best safety device in any aircraft is a well-trained crew. To that end, we have continually invested in technology and training innovations that provide the highest possible fidelity training to our customers, both commercial and military. In support of that objective, FlightSafety is focused on designing, manufacturing, and sustaining high-fidelity training devices intended to offer the most realistic immersive training environment possible. Our presentation will address the current state of technology in simulation, explain initiatives we are currently pursuing, and posit future areas for innovation, all with an eye towards continuing to enhance the realism of the training experience of our customers.

BOX 2-6

Federal Aviation Administration

Jeffery A. Schroeder, Chief Scientific and Technical Advisor
Flight Simulation Systems

The Federal Aviation Administration (FAA) regulates simulators for pilot training and uses simulators to train air traffic controllers, site new control towers, design airspace procedures, and develop unmanned aircraft systems requirements. This presentation focuses on simulators for airline pilot training only. Piloted simulation represents the largest and most sophisticated component of the FAA's responsibility in simulation, and these simulators must comply with federal regulations before they are used in pilot training. Airline pilots fly the simulator once or twice per year for about three days. Most of that time covers mandated training items, but an airline typically adds specialized training deemed important based on analysis of their operations. Once a year, pilots must pass a proficiency check in the simulator. The accident rate in the United States suggests that this process is satisfactory, as the rate continues to decrease with the continued increase of simulation use.

Naturally, these simulators still have limitations. This limitations fall into two categories: (1) the device is not capable, or (2) the device is capable, but is not used for the purpose. The latter category is not a limitation of the device itself, but of its application. Instances in the first category include (a) fully simulating the environment outside of the aircraft such as air traffic control and surface vehicles; (b) the lack of in-flight surprise; (c) motion cueing differences, especially normal and lateral load factors; (d) poor fidelity in wake vortex encounters; (e) stall modeling; (f) physical effects of icing; (g) stability and control fidelity near envelope edges; and (h) the landing experience is still different from flight. Items in the second category include (i) not demonstrating some key pilot-vehicle interface functions and (ii) simulating events in conditions that differ from those that typically occur in flight (e.g., go-arounds, stalls).

Besides trying to improve the above limitations, additional simulator enhancements may further improve aviation safety. These enhancements include (1) being able to get yesterday's incident into training instantly to prognostically prevent tomorrow's accidents; (2) developing scenarios that invoke grey decision making and that expose common human errors; (3) defining the relation between simulator fidelity and training value; (4) adjusting the challenges posed in simulation to be commensurate with the trainee's skills; (5) relying more on frequency-domain measures to ensure that the simulator and aircraft have similar flying qualities; and (6) better modeling of slippery runway conditions.

As far as technologies, approaches, and techniques required to satisfy this to-do list go, much of it is simply time, money, and the will power to do it. Many of the improvements are evolutionary instead of revolutionary. Probably a lot can be done with standardization so that improvements can be made more collectively, rather than in an individual piecemeal approach. However, incentives to standardize and the enthusiasm for doing so have not been self-evident. Also, the pressure to keep training costs manageable necessitates that hard decisions be made on what not to do if more is added to a training session.

BOX 2-7

National Aeronautics and Space Administration

Bimal Aponso, NASA Ames Research Center

NASA Ames Research Center is home to several high-fidelity research flight and air-traffic control simulation facilities which, together with an experienced workforce, produce high-quality research data and findings that have proven to be applicable in the real world. These assets include the Vertical Motion Simulator (VMS), Crew Vehicle Systems Research Facility (CVSRF), Future Flight Central (FFC) air traffic control tower simulator, and several air-traffic control (ATC) simulators.

The VMS combines a high-fidelity simulation capability with an adaptable simulation environment, enabling customization for numerous human-in-the-loop research applications. The distinctive feature of the VMS is its unparalleled large-amplitude, high-fidelity motion capability. In over 30 years of continuous operation, the VMS has contributed significantly to the body of knowledge in a range of disciplines directly benefiting several aerospace programs and flight safety, including the design and development of flight control systems for the Joint Strike Fighter, Space Shuttle Orbiter, and rotorcraft. It continues to be used for researching new vehicle configurations, vehicle control and safety, transfer-of-training, etc., by NASA, other government agencies, and industry.

The CVSRF includes two motion-based flight simulators: a Boeing 747-400 full-flight simulator and the reconfigurable Advanced Concepts Flight Simulator (ACFS). These simulators are primarily used to research air-traffic management concepts and procedures, advanced navigation and avionics concepts, and cockpit human factors. FFC is a full-sized control tower simulator with a 360-degree external field-of-view display system and reconfigurable system architecture. FFC and the ATC simulators are used to test air-traffic management automation and decision support tools and demonstrate their feasibility in a realistic environment prior to technology transfer for implementation in the National Airspace System.

To support integrated simulations and flight tests for NASA's Unmanned Aircraft Systems (UAS) in the National Airspace System Project, NASA developed a distributed test environment incorporating live, virtual, constructive (LVC) concepts. Development of the software enabling the LVC is conducted primarily at the Distributed Simulation Research Lab at NASA Ames. The LVC components provide the core infrastructure supporting simulation of UAS operations by integrating live and virtual aircraft in a realistic air-traffic environment. This provides the ability to conduct tests more efficiently by promoting the use of existing distributed assets. The LVC infrastructure was used in several human-in-the-loop simulations to evaluate acceptance of Detect and Avoid advisories used by UAS pilots to maintain well clear of other virtual traffic and to negotiate maneuvers with air-traffic control. It is currently being used to support testing of self-separation algorithms between unmanned and manned aircraft in live flight. Further simulations with more comprehensive air traffic scenarios mixing live and virtual aircraft is planned.

In the current fiscal environment, maintaining and upgrading these high-fidelity simulation assets and retaining the skilled workforce necessary to meet future research needs is the primary non-technical challenge. Technical challenges include the ability to develop and participate in LVC-distributed simulations more quickly and with less cost expenditure on developing customized solutions. Potential solutions include determining and establishing interface definition standards for interacting simulation environments covering simulation models, communication protocols, information technology security, etc. Also, an improved understanding of the benefits of simulation and levels of simulation fidelity required for program risk mitigation and training effectiveness would better inform funding decisions on these assets.

BOX 2-8

The University of Toledo Interprofessional Immersive Simulation Center

Pamela Boyers, Executive Director, University of Toledo Interprofessional Immersive Simulation Center; Gerald Zelenock, Professor and Chairman, Department of Surgery, University of Toledo College of Medicine

The University of Toledo Interprofessional Immersive Simulation Center (UT-IISC) is a highly advanced 65,000 sq. ft. simulation facility purpose-designed to transform the training of health care providers and develop new methods for improving human performance and effectiveness. With a unique clustering of three highly integrated, state-of-the-art simulation centers, the UT-IISC provides the ideal venue in which medical/industry partnerships are created for the purpose of developing and testing of new processes, products, and devices. In addition, UT-IISC has a wide range of subject matter experts available to advise, support, and help test the development of new products—including the potential of partnering to conduct human factors research and develop autonomous health systems.

A Tri-Center Simulation Training Concept

The UT-IISC houses three distinct, yet integrated, simulation centers:

- A *Modeling and Simulation Center* that incorporates 3-D and Virtual Immersive Reality (VIR) and holographic technology with a 5-sided light-emitting diode (LED) VIR, a large, curved LED CAD Wall, a Holographic Theater, Display Wall, and Industry Collaboration Spaces.
- An *Advanced Simulation Center* that houses real hospital equipment and human patient simulators in a wide variety of simulated healthcare settings—including an *Elliptical Virtual Hospital* that incorporates an Intensive Care Unit, Labor and Delivery Room, Trauma Suite, and a Pediatric Unit around a central control tower. The human patient simulators are computer "driven" through medical scenarios from this control room that is surrounded by one-way glass. This design enables the simulation scenarios to be easily viewed from a raised vantage point. All virtual clinical environments have cameras and microphones installed in the ceilings to record each training session. Critical events that occur during the LVCEs are tagged by the simulation capture system and participants review the exercise in adjacent debriefing rooms utilizing audio and visual recordings—along with the physiological data (clinical responses) of the human patient simulators.
- An *Advanced Surgical Skills Center* containing 17 surgical bays and procedural rooms is equipped with advanced surgical equipment that includes up-to-date instrumentation and a wide range of surgical scopes. The center operates in partnership with surgical instrumentation companies who help support the learning and research activities by providing equipment and staff for procedural skills and product development workshops.

From both the training and research and product development perspectives, it is possible to use all three centers to achieve the desired objectives. For example, one can "fly through" a human heart using the VIR in the Modeling and Simulation Center, then practice conducting a "Code Blue" as a team member in the Advanced Simulation Center, followed by conducting cardiac procedures in the simulated surgical suites in the Advanced Surgical Skills Center.

Promoting interdisciplinary collaboration and human factors research, the UT-IISC supports the development of procedural and communication skills through the ongoing development of reliable, valid methods of competency assessment. The ultimate goal for the UT-IISC is to focus on how simulation and LVC exercises in replicated clinical settings can improve the outcomes of care through enhancing the efficiency and accuracy of individuals and teams—ultimately reducing the costs of healthcare.

To transform the education of health professionals, the UT-IISC is utilizing a convergence of advanced simulation technology to help break down barriers (stove pipes/silos) between professions by promoting collaborative practice and using simulated clinical scenarios to enhance the performance of individuals and teams. The overarching mission of the UT-IISC is improving healthcare outcomes—with a strong emphasis on improving patient safety. The wide spectrum of modeling and simulation modalities available in the UT-IISC place the University of Toledo in a position to utilize "disruptive technologies" to transform the medical learning and research environment. Through the provision of interdisciplinary simulation and clinical simulation experts, the UT-IISC welcomes collaboration with many disciplines, including the U.S. military, in improving the outcomes of training and the design and testing of new products, processes, procedures, and systems.

BOX 2-9

State University of New York at Binghamton

*Frank Cardullo***,** *Professor of Mechanical Engineering*

The presentation aims to illuminate some of the flight simulation technology areas that present potential obstacles to successful pilot or other crewmember training. The simulator is discussed as a complex, dynamic, man-machine system in which the human operator is central to achieving the goals of exercise. It will treat technology issues of dynamic system simulation, human perception, and behavior in the context of a control theoretic approach. A major advantage of this approach is that, if applied appropriately, it will yield quantitative metrics of the simulator as a training device. It has been demonstrated that when certain anomalies occur in a flight simulator, such as visual or motion artifacts or the absence of certain cues necessary for proper execution of the task, that pilot performance metrics may remain constant but control behavior is altered. The discussion will include an introduction to some of the signal-processing techniques that can be used to quantitatively analyze pilot control behavior. Some examples will be presented, such as in the case of uncompensated delay in the various dynamic systems and the Objective Motion Cueing Test recently developed that quantifies in the frequency domain the effects of the motion cueing algorithm on the total motion system dynamics. The talk will conclude with some suggested areas of development.

3

Committee Member Observations on Adapting Additional Simulation Techniques for the Air Force

AREAS WHERE THE AIR FORCE COULD BENEFIT FROM ALTERNATIVE USES AND TECHNOLOGIES

A plethora of observations resulted from the presentations in Chapter 2. This section begins with extensive observations regarding future simulation architectures (Box 3-1, Box 3-2, and Figure 3-1, with associated explanation).

Committee member observations touched on the broad concepts above. First, Don Fraser, committee co-chair, and several other committee members were optimistic that, based on the earlier presentations, a significant part of this architecture concept is already in place (e.g., in the distributed mission operations network known as DMON). These committee members noted that movement forward can thus evolve in stepwise fashion with advances sized to meet specific training needs. (Note: Col Nathan Hill, Chief of ACC Flight Operations, mentioned issues in this area: "How many networks are too many? What type of networks do we need? What are the second and third order effects of shutting down and consolidating networks?") John-Paul Clarke opined that the Air Force needs a modular-flexible framework as a strategy on which to hang tactics and mechanisms to promote convergence versus a large program of record. He went on to say that it is necessary to know what standards to use. John Corley offered that the development of an intellectual architecture for live, virtual, constructive (LVC) simulation must occur prior to contracting for the physical architecture. Mr. Corley supported the use of the Drew-Robinson architecture concept. Mr. Corley believes the intellectual construct should not demand investment but provide a framework for decision makers to "opt in" where LVC supports learning opportunities not available through other methods, or where value is enhanced. He stated that the system design must be sufficiently adaptive to delivery of knowledge that, on the whole, delivers learning that is more rapidly assimilated and retained for longer periods.[1]

Committee co-chair Ray Johns offered that having established standards will allow the Air Force to have lower life-cycle costs. In a related topic, Michael Zyda noted that the U.S. government has failed miserably in simulator standards. He said, "Why not use open source procedures and processes?" Ex-post facto standards are hard to do, and very expensive. Dr. Zyda stated that the National Research Council's 1997 report *Modeling and Simulation: Linking Entertainment and Defense*, which he chaired, raised almost all the same issues with respect to the internetworking of defense simulations.[2] The lengthy architecture dialog led to the following additional key themes.

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[1] Bimal Aponso, Chief, Aerospace Simulation Research and Development Branch, a suggested using a phased approach to developing the common architecture using limited operational scenarios. The stated aim of this approach is to reduce the risk of integrating LVC components. Large-scale demonstrations and tests are inherently difficult to assess in terms of effectiveness due to the sheer scale of the variables involved. A phased build up to a large scale test using smaller, easier to measure, operationally relevant scenarios may be a better approach.

[2] For additional information, see National Research Council. *Modeling and Simulation: Linking Entertainment and Defense*, Washington, D.C.: The National Academies Press, 1997.

BOX 3-1

Observations on Path Forward for Integrating Air Force LVC Efforts

Pamela Drew, Committee Member

1. The implementations of live, virtual, constructive (LVC) simulation for training currently underway in the Air Force, Navy, and elsewhere are being developed in independent, stovepipe, and ad hoc fashion, which results in a platform-centric capability with simulator-simulator (hardwired) interfaces, disintegrated networks, and duplicative and similar, but unstandardized and unshared, data and mission sets. An alternative, and what is needed, is an approach that creates a common architectural approach in which LVC simulations can be "plugged" into an integration LVC backbone or integration architecture—hereafter referred to as ILVC-IA. Figure 3-1, from co-member Harry Robinson, illustrates this type of architecture.

a. In this architecture, there would reside reusable data for terrain, weather, threat information, blue tasking, etc. It would also contain reusable mission models, mission logic and rules, and simulators that could be re-purposed and used in various applications or instances of ILVC training sessions. The live or VC simulations would be integrated into this environment via standardized interfaces for communications and data links, for SIM via DIS and HLA, and the data passed would have to conform to standardized access interface protocols. Using this common integration architecture and enforcement of standards, a proprietary solution can still be integrated as long as it conforms to the interface and data access requirements.

b. This architecture can be put into use to support the entire range of desired combinations of LVC to support all missions from the "high end" Combat Air Force (CAF) requirements to more routine VC training scenarios. These mission scenarios create use cases of the architecture and results in specific applications or instances (e.g., an F-35 Live pulling VC world view of KC-46, AWACS, weather, etc.).

c. Of note, real-world sensors can also be integrated as feeds into the system, thereby bringing "reality" to the simulation. Obvious examples are for terrain and weather as part of the "live" feed, as well as other live assets.

d. Finally, security was referenced in multiple ways as a gap or obstacle by various presenters. In the ILVC-IA, security would have to be addressed. A few different elements would include encryption for the transport layer; multilevel security for crossing classification levels; role-based, access-control-type capability for authentication and authorization; and physical security for facilities.

2. By creating this new architecture, it would be possible to transform from a platform-centric view to a reality-centric view, enable more rapid integration of simulated and live assets, and enable far more efficient development of training capabilities.

Theme 3. Currently, live, virtual, and constructive training efforts are evolving in a largely ad hoc, stovepiped, and somewhat inefficient fashion. This situation suggests Air Force consideration of a different architectural approach that would be world-centric—open, pluggable and playable—rather than platform and contractor proprietary centric. This world-centric construct would contain common elements and live data, such as weather, terrain, threats, with an array of specific simulation platforms around the periphery drawing information from the common databases as opposed to utilizing their own proprietary database (Pamela Drew, Harry Robinson).

Theme 4. There are indications that some elements of the Air Force simulation architecture currently have these world-centric enterprise characteristics, so continued pursuit of an enterprise-level solution to live, virtual, constructive training could be very beneficial (Pamela Drew, Harry Robinson).

3. While this can be viewed as a technical architecture, the Air Force sponsors see it as providing a framework to articulate potential investment needs and to prioritize "where the next dollar should be spent." CAF and Mobility Air Forces (MAF) representatives both commented that, of the data sets presented during our general discussion, geographic, terrain, and threat sets were the priority.

4. CAF has an emergent and urgent need to bring VC simulation to augment F-35 Live to enable training due to constraints stated in the workshop. These are a combination of the decision not to allow full capability in live training, amongst others.

5. There is a need to organize the development of such an architecture through a clear authority structure, which would lead the architecture, standards, interface, and reusable asset-data-capability development. Note the goal should be to leverage all that can be reused or adapted to that which already exists.

6. The advanced technology demonstration (ATD) presented by Wink Bennett (Air Force Research Laboratory, AFRL) is an example of one "bottoms-up" instance of LVC underway. This could be harnessed and adapted as needed to become a first instance to begin implementation of the ILVC-IA architecture.

7. Just as such an architecture would benefit the Air Force, there is an analogous gap and application across the services—Department of Defense (DoD) wide. The Navy is also just beginning the LVC journey, developing yet another (mostly separate) capability operating on the JBUS, which appears to be the counterpart to the Air Force distributed mission operations network (DMON). Getting the services to use the Defense Information Systems Agency Global Information Grid (DISA GIG) via the Joint Information Environment (JIE) will facilitate the transport/network layer of integration.

8. There are various efforts underway that address some or perhaps all of the proposed ILVC-IA. These include the J7's JLVC Vision 2020, the AFRL ATD, Air Force Special Operations Command Ops training, and industry efforts (e.g., Boeing, Lockheed, Northrop capability). These efforts should be assessed and leveraged into this unified ILVC-IA capability as possible and appropriate.

9. There is a need for a single authority within the Air Force to define architecture, enforce standards, to select and maintain reusable content of the ILVC-IA, including, but not limited to, reusable data and mission sets. The authority should also create and drive execution against a near-, mid-, and long-term roadmap and associated plan that demonstrates capacity to integrate legacy capabilities (both government and industry) with new capabilities. In addition, and as important, are a new governance model, communication model, and stakeholder engagement.

10. There were a variety of technology developments and improvements for human-in- the-loop interfaces (e.g., Google Glass) and techniques (e.g., motion) that can be included in a continuous technology refresh sub-task in the oversight and development of the ILVC-IA. These assessments must also be specific to training objectives.

Committee members had additional observations in other areas. First, Robert Allardice noted that, in connection with the Boeing presentation, a benefit is that current and emerging technology for assessment and gaming technology may provide significant growth in our understanding of learning. He also noted that mobile technology has changed how people make decisions; we ought to heavily leverage mobile technology for enhancing learning and substituting training. Mr. Allardice went on to say that more discussion should take place on what the Air Force understands about "how" humans can best learn "today" based on significant discoveries and advances within the past decade. He said it is important to tailor the right learning tool for the right learning objective and place competency in the right platform. Finally, Mr. Allardice shared that, regarding the medical presentations, there are tremendous lessons to learn from collaborating with the medical community. That community, he noted, is advancing understanding of learning, education, and training, making significant advances in several technologies that could help the Air Force prioritize and match content to learning platforms. Leveraging technology to deliver an experiential learning environment similar to medical simulation is important.

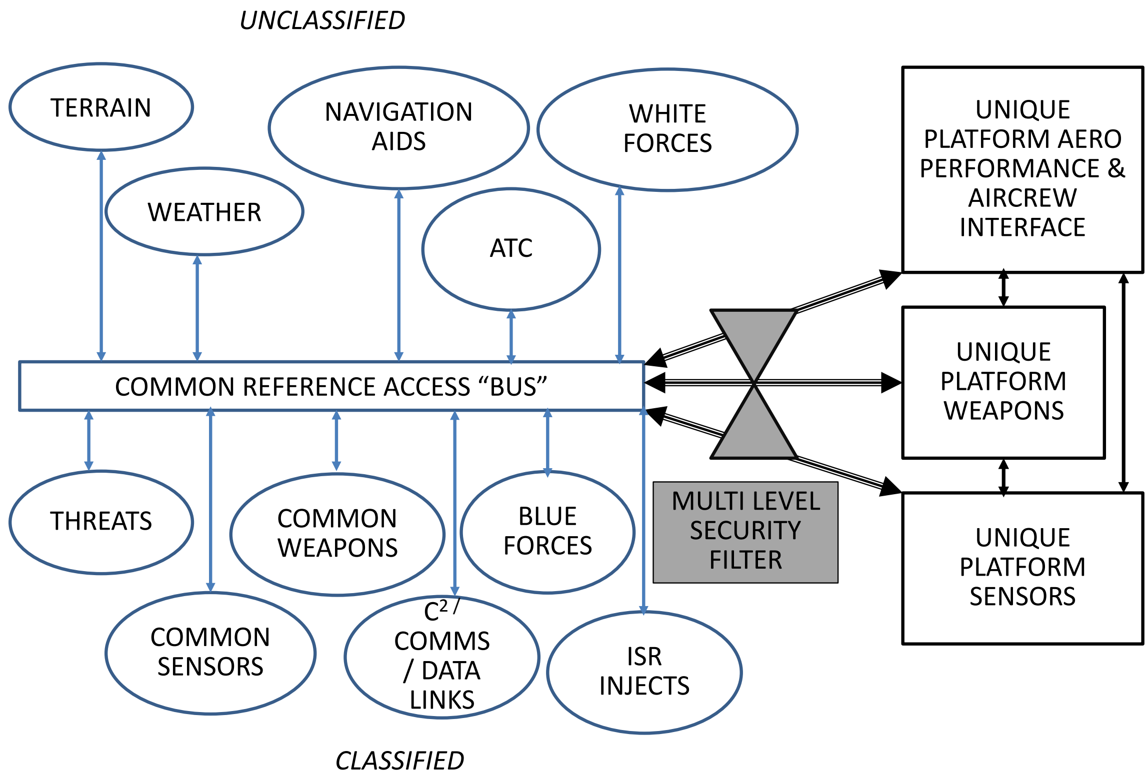

FIGURE 3-1 Notional architecture for U.S. Air Force live, virtual, constructive training.

BOX 3-2

Explanation of Notional Architecture for U.S. Air Force LVC Training

Harry Robinson, National Program Manager, Veterans Health Administration (VHA) Simulation Learning Education and Research Network (SimLEARN) (Committee Member)

Simulation-based training environments for the Air Force would benefit from an architecture using Common Reference Access "Bus" that would serve as a shared information provider simultaneously supporting generation of mission characteristics and events necessary to provide realistic training. Components would contain grouped databases that would drive LVC simulations accessed from training platforms unique to specific aircraft types, models, and series. Each component database would be established and subsequently maintained to achieve necessary level of currency. The respective modules could be characterized as Unclassified (including terrain, weather, navigational aids, air traffic control, and white force generation) or Classified (including threat, enemy orders of battle, common sensors [similar across multiple aircraft], common weapons [air-to-air, air-to-ground, similar across multiple aircraft], command and control, communications, data links, blue force generator, and intelligence-surveillance-reconnaissance scenario injects. Simulation execution of unique platform models for aerodynamic performance, aircrew interface (e.g., controls and displays), weapons, and sensors would integrate with the components' data accessible on the common reference access "bus" as controlled or limited by a multilevel security filter. Specific aircraft simulators would plug in to the common bus. Advantages of this construct include (1) reduction in need for stove-piped and proprietary solutions for each type aircraft simulator, (2) standardized component databases that can be independently established, (3) ease for maintaining database currency, (4) networked simulations executed in a shared environment, and (5) simulation-based exercises that support specific platform security program requirements.

John Corley offered that the ability to deliver learning for training is important and that consideration should be given to the changes in how airmen will "learn" and the related future demographics. (Note: Col Hill also had a comment in this area: "The new generation learns differently than most of us. We need to figure out the best way to teach them.") Steven Detro observed that, as a substitute for some training, higher-fidelity simulation technologies are now enabling more training to be accomplished in virtual reality. He went on to note that continued analysis of the potential benefits that virtual reality simulation could offer to each area of training should be considered. With a blend of different training media and training devices, Mr. Detro offered that a greater percentage of training sorties or training events could move into simulators; these hours should complement current live fly hours. (Note: Current acquisition policies have forced the Air Force to find lower-cost technology.) Mr. Detro believes the Air Force could use (1) performance measurement technologies already developed by the Air Force Research Laboratory (AFRL) to increase the ability to objectively measure the effectiveness of training;[3] (2) the "science of learning" cognitive modeling products of the AFRL to assist in the development of more efficient learning delivery methods for training; and (3) immersive technology advancements to deliver training information to match the learning preferences of students.

Several committee members provided final thoughts in this area. First, Ray Johns offered that independent research and development by industry has advanced knowledge of simulation applications and technologies. Second, Harry Robinson noted that, to meet Air Force needs, the following outside capabilities and technologies are most useful: adaptive learning and intelligent tutoring, cloud computing, common accessed resources for data, real-time representations and feedback loops that avoid latency issues, and multiplayer interactive gaming that builds teamwork and communication skills. Lastly, Michael Zyda noted that, with respect to the CAE presentation, open standards for all parts of the simulation enterprise will decrease costs and make better systems. He said that, regarding the Lockheed Martin presentation, alternate simulation systems become possible with head-mounted displays, and perhaps the Air Force should look at head-mounted displays and augmented reality technology for some of what it is doing. He also thinks that networked simulators have latency problems; perhaps look at what the game industry does for this.[4]

HOW LIVE, VIRTUAL, CONSTRUCTIVE TECHNIQUES COULD IMPROVE AIRCREW TRAINING

Several committee member comments applied to how techniques for LVC simulation for training could improve aircrew training, although there are links back to other messages in this report. For example, Robert Allardice noted that at one point simulator training was secondary; however, advances in technology have led to LVC as the primary way to train for the mission. Mr. Allardice went on to say that he thinks the best way to frame LVC is not that it will improve training. It is that advances in technology and modern applications drive an LVC "imperative." Mr. Allardice noted that all training can benefit to some extent; the key seems to be to develop an architecture from which specific applications can draw, based on the risk profile the Air Force chooses based on a particular mission set. John Corley was of the opinion that the Air Force needs to make prudent investments that enable needed enhancements to or development of the enterprise intended to yield a "realistic" training environment. Mr. Corley noted that

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[3] There was a comment from an operational pilot in the audience on the need to measure training effectiveness. The pilot said that when developing a training capability, particularly of threat environments, it was important to ensure that the probability of success in the simulator be equivalent to that in an actual situation. This highlights the overall issue of ensuring a viable training effectiveness validation method is developed in tandem with LVC simulation capability.

[4] For best practices, consider the following publication: Johns Hopkins University Applied Physics Laboratory, *Best Practices for the Development of Models and Simulations: Final Report*, NSAD-R-2010-037, Laurel, Md., June 2010, available at http://www.msco.mil/MSBPD.html.

investments must consider the temporal dimension, bit-sized approach toward the delivery of the LVC capability. The following themes arose during the discussions:

Theme 5. Advances in technology and increasingly complex user needs have led to live, virtual, constructive training as the primary way to train for some missions (Robert Allardice).

Theme 6. Substantial benefits could accrue to the Air Force if it relied on open systems and acquired data rights as the model when procuring new systems. Enforcing compliance to more interoperable, related standards could lead to a "plug and play" environment (Pamela Drew, Michael Zyda).

Theme 7. Research into the "science of learning" is indicating that young people, who have considerable computer skills compared to previous generations, learn in very different ways compared to older generations. Future architectures and systems would benefit by taking this knowledge into account (adaptive learning) (Donald Fraser, Steve Detro).

SUGGESTED AREAS FOR POSSIBLE FOLLOW-ON STUDY

Ray Johns indicated that the Air Force sponsors of this workshop requested that there be no follow-on study. Nevertheless, some committee members suggested a few areas that the Air Force may wish to delve into more deeply; these areas are listed below.

1. What is the full set of requirements for Air Force LVC simulation for training?
2. What is the optimal standard and architecture that the Air Force should strive for? What is the roadmap for the architecture?
3. How can multilevel security be dealt with—through a study in its own right? and Should such a study be classified?
4. What can be done about adaptive learning?
5. What is the need, if any, for a change in Air Force governance with respect to LVC simulation for training? What organizational and budget changes need to be made for an effective LVC simulation for training capability across all missions (with the F-35 as the first system priority)?

Appendixes

A

Biographical Sketches of Committee Members

RAYMOND E. JOHNS JR., *Co-Chair,* is responsible for FlightSafety International's global government and military programs. He began working with the company in 2013 as a senior advisor and was named senior vice president in January 2014. Before assuming his current role, Gen. Johns commanded the United States Air Force Air Mobility Command, Scott Air Force Base (AFB), Illinois. The mission of the Air Mobility Command is to provide rapid, global mobility, and sustainment for the U.S. armed forces. Gen. Johns graduated from the U.S. Air Force Academy in 1977. He has served as a program manager and source selection authority; an experimental test pilot, having flown some 83 different aircraft; and he was the chief test pilot and test program manager for the VC-25 Air Force One Replacement Program. He was chosen as a White House fellow in 1991, where he was a senior staff member in the Office of National Service. He served at Headquarters US European Command in security assistance, strategy, and congressional affairs and at Headquarters US Pacific Command as deputy director of strategic plans and policy. He commanded a test squadron, operations group, and airlift wing, and he was the director of mobility forces for operations in Bosnia and was responsible for strategic airlift operations in Iraq and Afghanistan. Gen. Johns served as deputy chief of staff for strategic plans and programs, Headquarters U.S. Air Force, Washington, D.C., where he developed, integrated, evaluated, and analyzed the U.S. Air Force annual budget and the Air Force Long-Range Plan to support national security objectives and military strategy. He retired from the U.S. Air Force effective January 1, 2013.

DONALD C. FRASER, *Co-Chair,* has broad research and development management experience and is the founder and retired director of the Boston University Photonics Center. Dr. Fraser has had a distinguished career managing the development of high technology enterprises, both in the private and public sectors. Dr. Fraser joined the Massachusetts Institute of Technology's (MIT's) Instrumentation Laboratory (which became the Charles Stark Draper Laboratory in 1973) as a member of the technical staff; later he served as the director of the Control and Flight Dynamics Division; vice president of technical operations; and executive vice president and chief operating officer. From 1990 to 1991, Dr. Fraser was deputy director of operational testing and evaluation for command, control, communications, and intelligence at the Department of Defense (DoD). After Senate confirmation, he was appointed Principal Deputy Under Secretary of Defense (Acquisition) from 1991 to 1993. From 1994 to 2006, Dr. Fraser was the director of the Boston University Photonics Center and a professor of engineering and physics. His honors include the Defense Distinguished Service Medal. Dr. Fraser has served on the NASA Advisory Council. He is a member of the National Academy of Engineering, served on the National Research Council's (NRC's) Aeronautics and Space Engineering Board, chaired several NRC committees, and was a member of many other NRC committees. He received his Sc.D. in instrumentation from MIT.

ROBERT R. ALLARDICE founded Allardice™ Enterprises, Inc., in 2013 after successfully serving in the U.S. Air Force for more than 33 years, reaching the rank of Lieutenant General. With 16 years of senior executive experience and a remarkable record of achievement in the Air Force, Mr. Allardice is recognized as an innovative pioneer leading transformation in modern complex global systems. His experience leading organizations ranging from 100 to 133,000 people, culminated in the position of vice commander of Air Mobility Command (AMC). In that capacity, he ran corporate oversight of a $20 billion operation with broad responsibilities from operations and training to programming, installation oversight, and financial management. Additionally, he sat on the U.S. Air Force Corporate Board and several operational governance boards. Prior to his duties at AMC, as commander of 18th Air Force, he led the U.S. military global air mobility enterprise through transformation and multiple global operations. His leadership of the military's global air transportation system is credited with unique applications of virtual and collaborative tools redefining modern staffing methods and driving significant increases in effectiveness and efficiency. Prior experiences include oversight of the U.S. Central Command Security Assistance program for Central Asia, and the Mideast, working with 20 different countries to refine security cooperation agreements. Also, he led the team building the U.S. military strategy for the Mideast, Central Asia, and Persian Gulf. Additional recent experience includes command of the Coalition Air Force Transition Team in Iraq, where he successfully built a program to reestablish the Iraq Air Force. Mr. Allardice holds an M.S. in systems management from the University of Southern California.

JOHN-PAUL CLARKE is an associate professor in the Daniel Guggenheim School of Aerospace Engineering, with a courtesy appointment in the H. Milton Stewart School of Industrial and Systems Engineering, and director of the Air Transportation Laboratory at the Georgia Institute of Technology. He received S.B. (1991), S.M. (1992), and Sc. (1997) degrees in aeronautics and astronautics from MIT. His research and teaching in the areas of control, optimization, and system analysis, architecture, and design are motivated by his desire to simultaneously maximize the efficiency and minimize the societal costs (especially on the environment) of the global air transportation system. Dr. Clarke has made seminal contributions in the areas of air traffic management, aircraft operations, and airline operations—the three key elements of the air transportation system—and has been recognized globally for developing, among other things, key analytical foundations for the Continuous Descent Arrival and novel concepts for robust airline scheduling. His research has resulted in significant changes in engineering methods, processes, and products—most notably the development of new arrival procedures for four major U.S. airports and one European airport—and changes in airline scheduling practices. He is an associate fellow of the American Institute of Aeronautics and Astronautics (AIAA) and a member of the Airline Group of the International Federation of Operations Research Societies, the Institute for Operations Research and the Management Sciences, and Sigma Xi. His many honors include the AIAA/AAAE/ACC Jay Hollingsworth Speas Airport Award in 1999, the Federal Aviation Administration (FAA) Excellence in Aviation Award in 2003, the National Academy of Engineering Gilbreth Lectureship in 2006, and the 37th SAE/AIAA William Littlewood Memorial Lecture Award (awarded in January 2012).

JOHN D.W. CORLEY is an experienced strategic thinker and skilled international collaborator in the development and utilization of weapons systems. He entered the U.S. Air Force Academy in 1973. His aviation career includes more than 3,000 flying hours with combat experience. He commanded at flight, squadron, group, wing, and major command levels. His staff positions comprised a mix of service and joint duties in Tactical Air Command, Pacific Air Forces, U.S. Air Forces Europe, Air Combat Command, Headquarters U.S. Air Force, and the Joint Staff. Gen. Corley retired from the U.S. Air Force after 36 years on active duty. His final assignment was commander, Air Combat Command (ACC). At ACC, he directed the planning, organizing and training to assure combat-ready forces for 156,000 personnel operating 1,200 aircraft at more than 200 worldwide locations. He orchestrated the development of strategy, doctrine, concepts, and procedures for air power employment. Previously, he served as vice chief of staff, U.S. Air Force, responsible for the oversight of 680,000 active-duty, Guard, Reserve, and civilian personnel serving in the United States and overseas. Other key staff positions included the following: principal deputy, assistant secretary of the Air Force for acquisition; military director, member of the U.S. Air Force Scientific Advisory Board; and director, studies and analysis, Headquarters U.S. Air Forces in Europe. Since retiring from active duty, Gen. Corley has become an independent consultant. He serves on several boards in addition to consulting for a number of defense and aerospace industry corporations. He served on the board of the Air Force Association to educate the public about the critical role of aerospace power in the defense of our nation, advocate for aerospace power, and support the Air Force family and aerospace education. Additionally, he is a trustee of the Falcon Foundation, providing scholarship funding for promising young men and women aspiring to attend the U.S. Air Force Academy.

STEPHEN D. DETRO directs a team at Lockheed Martin in new business forecasting, business capture, and marketing activities focused on domestic and international simulation and training opportunities. Mr. Detro has more than 35 years as a business development executive representing companies and leading multi-disciplined teams providing simulation and training technologies and solutions for DoD and international Air Forces. He is a retired lieutenant colonel from the U.S. Air Force Reserve and Air National Guard, with 28 years total service with sustained combat mission ready status as a U.S. Air Force Reserve and Air National Guard fighter pilot, while maintaining a full-time civilian career. He is a combat mission-qualified pilot in the F-16A, F-4D, A-7D and F-100D fighter aircraft and a command fighter pilot with more than 2,300 hours and 4 years of enlisted service in aircraft maintenance. Mr. Detro is also currently protocol officer and conference chair emeritus for the Interservice/Industry, Training, Simulation and Education Conference and former chairman of the National Training and Simulation Association Executive Committee. Mr. Detro holds a B.S. in education from Wright State University.

PAMELA (PAM) DREW is executive vice president and president of information systems, a business area of Exelis, Inc., that is a leading provider of mission critical network solutions. These solutions leverage the group’s core capabilities that span the full life cycle of critical networks, including system architecture, design, development, deployment, integration, test and evaluation, operations, maintenance, sustainment, and modernization. These services are currently provided to U.S. government agencies, including the FAA, U.S. Air Force, U.S. Navy, U.S. Army, Defense Threat Reduction Agency (DTRA), and the intelligence community; additionally, the business includes a growing commercial, global aviation presence. Before joining Exelis, Dr. Drew was the senior vice president of Strategic Capabilities and Technology at TASC, Inc., leading an enterprise-wide team that provided systems engineering and integration, cyber security, financial and business analytics, and test and evaluation solutions to intelligence, defense, and federal and civil customers. In a prior role at TASC, she led the Enterprise Systems business unit that served defense and federal civil agencies, including DTRA, the Department of Homeland Security, and the FAA. Prior to that, Dr. Drew was sector vice president of business development for Northrop Grumman’s Mission Systems sector. Before joining Northrop Grumman in 2008, she was vice president and general manager for Boeing’s Integrated Defense and Security Solutions organization heading strategy and business generation in homeland and global security markets. While at Boeing, Dr. Drew also served as vice president and general manager of Boeing’s C3ISR business unit serving the U.S. Air Force, U.S. Navy, and several international customers including the United Kingdom, NATO, Australia, and Turkey. In a prior role, she led a significant portion of Boeing Phantom Works developing and transitioning technology across the commercial airplane and military businesses. Dr. Drew has held several leadership roles with NRC boards and committees, including as the vice chair of the Air Force Studies Board and on the “NextGen” Air Traffic Management committee for the Transportation Research Board. She also serves on the board of directors for University of Washington’s Applied Physics Laboratory. Dr. Drew has been named an associate fellow of AIAA. She also serves on the Strategic Advisory Councils to the Chancellor and Dean of Engineering at the University of Colorado, Boulder, where she earned her Ph.D. in computer science.

RICHARD V. REYNOLDS, General, U.S. Air Force (retired), is owner and principal of the VanFleet Group, LLC, an aerospace consulting company. He also serves as an independent/outside director for Allison Transmission Holdings, Inc.; Apogee Enterprises, Inc.; and Barco Federal Systems, LLC. He holds advisory board seats for Sierra Nevada Corporation and Electronic Warfare Associates-Government Systems, Inc. In a volunteer capacity, he has served as board chairman and CEO of the Air Force Museum Foundation, Inc., and as a member of the U.S. Air Force Heritage Program board of directors. In

2009-2011, he was chair of the NRC Committee on Evaluation of U.S. Air Force Preacquisition Technology Development and now serves on the Air Force Studies Board. Prior to his retirement in 2005, Gen. Reynolds was vice commander, Air Force Materiel Command. During his 34-years of active duty Air Force service, he commanded the Aeronautical Systems Center at Wright-Patterson AFB, Ohio, and the Air Force Flight Test Center at Edwards AFB, California. He was also program executive officer, airlift and trainers in the Pentagon and program director for several major weapon system acquisitions, including the B-2 Spirit. Gen. Reynolds is a graduate of U.S. Air Force Test Pilot School, Class 79B, and has more than 25 years of hands-on experience in the research, development, program management, and test and evaluation of aeronautical systems. He holds FAA certificates for airline transport pilot and flight instructor (glider), and his logbook shows more than 4,000 flying hours in 72 different military and civil aircraft. Graduating in 1971 from the U.S. Air Force Academy with a B.S. in aeronautical engineering, Gen. Reynolds has an M.S. in mechanical engineering from California State University and an M.A. in national security and strategic studies from the Naval War College. He is a fellow of the Society of Experimental Test Pilots.

HARRY M. ROBINSON is the SimLEARN National Program Manager for the Veterans Health Administration (VHA) Simulation Learning Education and Research Network (SimLEARN), which uses simulation-based clinical training for health-care providers and clinicians to increase and sustain workforce skills and improve veteran patient outcomes. As the hub for the VHA National Simulation Network, the SimLEARN National Simulation Center uses innovative and immersive training technologies in a safe learning environment to enhance diagnostic, procedural, and team communication skills to support quality care and the best possible quality of care. A veteran of the U.S. Navy, Mr. Robinson completed his active duty as the commanding officer of the Naval Air Warfare Center Training Systems Division leading over 1,100 personnel accomplishing full life-cycle acquisition of training solutions for the Navy. As a naval flight officer, he primarily flew the E-2C Hawkeye and commanded both an operational squadron and type wing. His combat experience includes strike, close air support, and air superiority missions over Iraq, Afghanistan, and the former Republic of Yugoslavia. Mr. Robinson retired at the rank of captain after 28 years of military service. Subsequently he was a senior associate with Booz Allen Hamilton, where he served as the Advanced Analytics Modeling and Simulation lead supporting Team Orlando, a collaborative alliance of governmental and nonprofit agencies, including DoD and the Veterans Administration, working to leverage simulation technology to improve employee performance. His focus was on providing live, virtual, and constructive simulation to support training solutions to improve human performance and accomplish individual and team training requirements. Mr. Robinson earned his commission through the Navy Reserve Officer Training Corps upon graduation from Pennsylvania State University in 1982 with a B.S. in computer science. He then earned an M.S. in aviation systems from the University of Tennessee and completed the Naval War College Command and Staff Course. He is currently pursuing a Ph.D. in modeling and simulation from Old Dominion University and completed a Medical Modeling and Simulation Certificate Program at the Naval Postgraduate School MOVES Institute.

MICHAEL J. ZYDA is a professor of engineering practice in the Department of Computer Science at the University of Southern California. He also directs the university's GamePipe Laboratory, which engages students in research and development of interactive games. He initiated two cross-disciplinary degree programs–a B.S. in computer science (games) and an M.S. in computer science (game development)—and doubled the incoming undergraduate enrollment of the Computer Science Department. Dr. Zyda is a pioneer in the fields of computer graphics, networked virtual environments, modeling and simulation, and serious games. His research interests include collaboration in entertainment and defense, and he has developed, for example, a game used by the Army for recruiting. He has served on numerous NRC committees advising DoD. Dr. Zyda is a national associate of the National Academies and a member of the Academy of Interactive Arts and Sciences. He received a Ph.D. in computer science from Washington University.

B

Workshop Speakers

NOVEMBER 17-19, 2014
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November 17, 2014

Air Mobility Command
Lt Gen Brooks Bash, Vice Commander, Air Mobility Command
Mr. Michael “Norm” Maloy, Chief, AMC Aircrew Training Plans and Programs, Air Mobility Command

Air Combat Command
Maj Gen James Post III, Vice Commander, Air Combat Command
Mr. Fred Van Wicklin (B3H), ACC/A3TO DMO, Air Combat Command

Air Force Life Cycle Management Center
Col Daniel Marticello, Chief, Simulators Division, AFLCMC/WNS

Air Force Requirements and Agency for Modeling and Simulation
Brig Gen Eric Overturf, Mobilization Assistant to the Director of Operations, Deputy Chief of Staff for Operations, Plans and Requirements, Headquarters U.S. Air Force

November 18, 2014

Air Force Special Operations Command
Col Steve Breeze, Chief of Training, A3/A3T

Air Force Research Laboratory
Dr. Winston “Wink” Bennett, Division Technical Advisor for Training and Assessment Research, 711 Human Performance Wing

U.S. Navy
Mr. Maynard Zettler, Director, Research and Engineering Naval Air Warfare Center Training Systems Division

National Aeronautics and Space Administration
Mr. Bimal Aponso
Mr. Jim Murphy

Lockheed Martin Mission Systems and Training
Mr. Rick Boggs, Senior Fellow

Federal Aviation Administration
Dr. Jeffery Schroeder, Chief Scientific and Technical Advisor for Flight Simulation Systems

CAE, Inc.
Dr. David Graham, Director of Technology Application

November 19, 2014

Boeing Company
Mr. Steve Monson, Chief Technologist, Technical Fellow-Simulation and Training

FlightSafety International
Dr. Nidal Sammur, Director of Engineering and Simulation

Medical Simulation
Dr. Pamela Boyers, Senior Advisor to the Chancellor and Executive Director for Clinical Simulation
Assistant Professor: Department of Surgery, University of Toledo

State University of New York, Binghamton
Dr. Frank Cardullo, Professor

Feedback from Workshop Co-Champions on Next Steps
Lt Gen Brooks Bash, Vice Commander, Air Mobility Command
Maj Gen James Post III, Vice Commander, Air Combat Command

U.S. Air Force Strategic Deterrence Analytic Capabilities: An Assessment of Tools, Methods, and Approaches for the 21st Century Security Environment

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COMMITTEE ON U.S. AIR FORCE STRATEGIC DETERRENCE MILITARY CAPABILITIES IN THE 21ST CENTURY SECURITY ENVIRONMENT

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AIR FORCE STUDIES BOARD

Preface

In 2012, the Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration, Headquarters U.S. Air Force and the Commander of the Air Force Global Strike Command, asked the National Research Council's (NRC's) Air Force Studies Board (AFSB) to conduct a workshop on what Air Force strategic deterrence capabilities would be required for the 21st century security environment. The AFSB agreed and organized a workshop to frame the issues and construct the terms of reference (TOR; see Appendix A) for a follow-on study. A summary of the workshop was approved by the NRC and submitted to the Air Force co-sponsors in early 2013.[1]

TERMS OF REFERENCE

At the Air Force's subsequent request, the NRC approved the terms of reference in March 2013.[2] The chair of the NRC then appointed a committee of experts in June 2013 to conduct this follow-on study.[3] The Committee on U.S. Air Force Strategic Deterrence Military Capabilities in the 21st Century Security Environ-

[1] NRC, 2013, *U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment: A Workshop Summary*, Washington, D.C.: The National Academies Press.

[2] The TOR are contained in Appendix A.

[3] Appendix B provides biographies of the committee members. The committee includes experts with experience in academia, government, and industry—combined with many years in Air Force nuclear weapons capabilities, strategies, and postures; decision and game theory; behavior-based profiling; risk management; operations research; and modeling and simulation.

ment met during 2013 and 2014 to gather and assess facts, discuss findings, and construct recommendations. The TOR include the following:

1. Identify the broad analytic issues and factors that must be considered in seeking nuclear deterrence of adversaries and assurance of allies in the 21st century.
2. Describe and assess tools, methods—including behavioral science-based methods—and approaches for improving the understanding of how nuclear deterrence and assurance work or may fail in the 21st century and the extent to which such failures might be averted or mitigated by the proper choice of nuclear systems, technological capabilities, postures, and concepts of operation of American nuclear forces.[4]
3. Discuss the implications for the Air Force and how it could best respond to these deterrence and assurance needs. Include in this discussion a framework for identifying the risks and benefits associated with different nuclear force postures, structures, levels, and concepts of operation.
4. Recommend criteria and a framework for validating the tools, methods, and approaches and for identifying those most promising for Air Force usage.
5. Recommend an appropriate mix of the classes of analytical tools affordable in today's austere financial climate, and identify what can be planned for by the Air Force as future improvements to this mix if defense budgets increase or decrease.

WHAT THIS STUDY SEEKS TO DO AND HOW IT GOES ABOUT DOING IT

The TOR basically direct the committee to identify the broad issues and factors to be considered in seeking nuclear deterrence of adversaries and assurance of allies in the 21st century and to evaluate and recommend tools, methods, and approaches for (1) understanding nuclear deterrence and assurance in the new security environment and (2) sizing forces appropriate for deterrence and assurance. The sponsor amplified the TOR by asking the committee to answer the following specific questions in the context of deterring adversaries and assuring allies:

- What analytic capabilities are needed to evaluate Air Force concepts and assertions about Air Force capabilities requirements as strategy is developed in the 21st century security environment?

[4] The committee interpreted items 2 and 3 of the TOR to mean that it should describe and assess analytic tools, methods, and approaches that would help both (1) in improving and understanding deterrence and assurance and (2) understanding how nuclear forces, posture, technological capabilities, and concepts of operations can improve prospects or mitigate failures. The committee and the Air Force understood that the study was not going to make recommendations about force structure and the like.

- How do we develop and validate future deterrence requirements and inject them into the joint requirements development process?
- What analytic capabilities can improve understanding of how nuclear deterrence and assurance work in the 21st century and how they might fail, and how might failure be averted by the proper choice of Air Force systems, technological capabilities, postures, and concepts of operation for American nuclear forces?
- Since what we believe about an adversary will change over time, can we develop systematic, integrated approaches to incorporate feedback, which would narrow the gap between beliefs about the adversary and knowledge about the adversary?
- How can we assist operational planners in matching Air Force capabilities, procedures, and actions to operational deterrence situations?
- How can we detect and evaluate adversary responses to deterrence actions?

The committee conducted its fact-finding and deliberations with those questions in mind.

While this study of deterrence and assurance has applicability to the U.S. Navy and its nuclear forces, the committee's focus was on those forces that the Air Force is responsible for: primarily the strategic systems (intercontinental ballistic missiles [ICBMs] and long-range bombers and stand-off, air-launched missiles) but also dual-capable aircraft for theater operations.[5]

The committee grappled with a number of issues in deciding how to approach the study. First, it understood that to produce a result that is useful to the sponsors, the study's recommendations should be cognizant of Air Force roles and authorities in the Department of Defense (DoD). As a military department, the U.S. Air Force has the legal authority to organize, train, and equip forces, which it then provides to joint combatant commands. The Air Force neither commands forces in peacetime or combat operations nor prepares operational plans for their use. The command and operational planning functions are done by functional or regional joint combatant commanders and their subordinate joint task forces, which, of course, does include Air Force personnel.[6]

[5] See Amy F. Woolf, 2013, *U.S. Strategic Forces: Background, Developments, and Issues,* Washington, D.C: Congressional Research Service, October 22 and Amy F. Woolf, 2012, *Nonstrategic Nuclear Forces,* Washington, D.C.: Congressional Research Service, December 19.

[6] The Air Force was established as a separate military department by the National Security Act of 1947, with its legal authorities (as were those of the Army and Navy) codified in Title X of the U.S. Code. This is what is meant when one finds the Air Force referred to as a "Title X organization." The Defense Reorganization Act of 1986, also known as the Goldwater-Nichols Act, changed the mission of the military departments. Goldwaters-Nichols limited their authorities to organizing, training, and equipping forces, while assigning the responsibility for commanding and operational planning to the functional and regional COCOMs. The responsibilities and alignments of the COCOMs are specified

This creates a known tension. Combatant commands (COCOMs) develop operational plans with short horizons relative to procurement and training timelines. The Air Force time horizon is much longer than those of combatant commands. In balancing readiness and modernization, the Air Force must organize, train, and equip for today's requirements (the current fight) *and* for the requirements not only of the next Future Years Defense Program (FYDP) but even for the "FYDP after next" (future contingencies). The question of what time horizon is appropriate for this study thus emerged as an important issue, which will be discussed further in this chapter.

The committee acquainted itself in broad terms with the process for establishing requirements in DoD. Prior to the reforms put in place by the Goldwater-Nichols legislation, the combatant commands had no formal role in the requirements process, nor did they have large supporting staffs that were expert in DoD's elaborate Planning, Programming, Budgeting, and Execution (PPBE) System. Goldwater-Nichols assigned leading roles in setting requirements for the Joint Chiefs of Staff (JCS) Chairman and brought the joint combatant commanders into the process.

Today, requirements are set by a joint system supporting the Secretary of Defense, where the Air Force has a voice but does not make final decisions. The Air Force has a seat on the Joint Requirements Oversight Council (JROC), which is chaired by the Vice Chairman of the JCS.[7] JROC is responsible for identifying, assessing, validating, and prioritizing joint military requirements, to include requirements for delivery systems but not for the nuclear stockpile. Stockpile requirements are addressed in the Nuclear Weapons Council (NWC), where the Air Force does not have a seat.[8]

in the Unified Command Plan, which is prepared by the JCS Chairman, reviewed and updated every two years, and approved by the President. There currently are nine COCOMs: Special Operations Command, Strategic Command, Transportation Command, African Command, Central Command, European Command, Northern Command, Pacific Command, and Southern Command. See Andrew Feickert, 2013, *The Unified Command Plan and Combatant Commands: Background and Issues for Congress*, Washington, D.C.: Congressional Research Service, January 3.

[7] In addition to changing the relationship of the armed services to joint combatant commands, Goldwater-Nichols created the position of Vice Chairman of the JCS, strengthened the role of the JCS Chairman and the Joint Staff, and gave the combatant commanders an important role in the process for establishing requirements. Under the Goldwater-Nichols reforms, the JROC was created. JROC is chaired by the Vice Chairman of the JCS. The Air Force is represented on the JROC by the Air Force Vice Chief of Staff.

[8] NWC is a joint DoD-National Nuclear Security Administration (NNSA) organization established to facilitate cooperation and coordination between the two Departments. Among other things, it addresses requirements for the nuclear stockpile. The NWC is chaired by the Under Secretary of Defense for Acquisition, Technology and Logistics (USD/AT&L). Members are the Vice Chairman of the JCS, the NNSA Administrator, the Under Secretary of Defense for Policy, and the Commander of STRATCOM. The NWC is supported by the Nuclear Weapons Council Standing and Safety Committee, where the Air Force does have a seat at the table.

In this complicated requirements system, the Air Force may seek to advance the understanding of the requirements for deterrence and assurance, but it does so primarily within the processes, assumptions, and lexicon of the joint force, and in a system where it does not have the final decision authority.

Of special importance to the committee's work was to gain an understanding of the role and perspectives of U.S. Strategic Command (STRATCOM). The committee reviewed STRATCOM documents (especially the *Deterrence Operations Joint Operating Concept*), received briefings from and interacted with STRATCOM staff, and devoted one of its fact-finding visits to STRATCOM headquarters at Offutt Air Force Base (AFB) in Omaha, Nebraska. The committee also acquainted itself with the views of STRATCOM's senior leadership.[9] Those have been taken into account in this report.

There are other major factors that were especially important to the committee's deliberations. One was the attempt in DoD to shift its force planning framework away from platform-centric thinking (the ICBM and the long-range bomber are delivery platforms) to a capability-based approach (where a capability is defined, in joint parlance, as "the ability to achieve a desired effect under specified standards and conditions through a combination of means and ways across the DOTMLPF (Doctrine, Organization, Training, Leadership, Materiel, Personnel, Facilities)."[10] DoD has developed an elaborate Joint Capabilities Integration and Development System (JCIDS) to support JROC. This establishes the framework and processes the Air Force must work within in DoD.

The committee found that, while thinking in terms of capabilities and effects, it is highly conducive to deterrence analysis (as will be discussed in subsequent chapters), constructing and defending a deterrence-related program within DoD, and successfully advocating the program to the White House and, ultimately, to the Congress, cannot be done simply by discussing capabilities and effects but must focus on platforms, e.g., the next generation bomber, ICBM, and SSBN. While it is currently U.S. policy to retain a traditional triad of strategic nuclear forces (which, for the Air Force, means retaining the ICBM and the long-range bomber) and to retain the Air Force dual-capable aircraft, it is unclear whether that will remain the case as arms control proceeds, budgets shrink, and hard choices must be made between force readiness and force modernization. There already have been advocates for eliminating the ICBM force and/or the nuclear-armed bombers and nuclear-

[9] Those views are readily available in statements prepared for testimony to Congress. Of special relevance were General Kehler's posture statement to the Armed Services Committees in March 2013 and his statement to the House Armed Services Committee Strategic Forces Subcommittee hearing on nuclear weapons modernization programs in October 2013, General Kehler relinquished command of STRATCOM to Admiral Haney on November 15, 2013.

[10] See http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afpd10-6/afpd10-6.pdf. Accessed November 21, 2014.

capable fighters and cancelling the Navy's SSBN-X as cost-saving measures. While the committee does not take a stand on such issues, it does acknowledge the debate as part of the unfolding security environment, which underlines the importance of providing the sponsors with the best possible tools, methods, and approaches for conducting sound deterrence analysis.

There are other considerations that were important factors in conducting this study, five of which deserve highlighting: (1) the meaning of *strategic* (as opposed to *nuclear*) deterrence; (2) the increasing importance of deterrence in regional settings; (3) nonstate actors; (4) the distinction between delivery systems and the nuclear weapons themselves, and (5) the possibility of changed circumstances, both positive and negative.

Like the workshop that preceded it, the committee spent considerable time discussing the fact that *nuclear* deterrence is not synonymous with *strategic* deterrence. There is a tension in these two concepts of deterrence, which is acknowledged and concisely expressed but not resolved in a white paper signed by senior Air Force civilian and military leadership on the Air Force Nuclear Enterprise and issued while this study was ongoing. Two passages from the white paper illustrate the tension:

> Nuclear weapons are not an anachronism of the Cold War but some concepts are outdated; the Nation requires fresh thinking to meet the deterrence challenges of today's strategic environment. Deterrence in the twenty-first century demands credible, flexible nuclear capabilities, linked to comprehensive strategies and matched to the modern strategic environment.
>
> Nuclear deterrence operations do not occur in a vacuum. All Air Force capabilities, including space, cyber, and conventional capabilities play a role in effective deterrence and provide options for decision makers. *Airmen must understand the interactions of these capabilities and how to integrate them to achieve the desired deterrent effects* (emphasis added).[11]

The white paper is silent on who is responsible for ensuring that airmen understand the interactions of these effects. That assurance appears to be a responsibility shared among a number of Air Force organizations, but with no common framework. That is true not only for the Air Force, but for DoD in general.

There does appear to be agreement within DoD and within the Air Force that *strategic* deterrence is *cross-domain* deterrence. This is emphasized in the STRATCOM documents the committee reviewed and in STRATCOM presentations. It is beyond the scope of this present study to provide a new analytic framework for cross-domain deterrence. It is reasonable to expect that the tools, methods, and approaches that this study addresses may help advance the analytic agenda for

[11] Air Force Headquarters, 2013, *Flight Plan for the Air Force Nuclear Enterprise,* Washington, D.C., June 26.

understanding cross-domain deterrence, even though they focus first and foremost on understanding how the nuclear dimension of deterrence is evolving.

Second, one of the major shifts in priority in U.S. deterrence thinking occurring over the years since the Cold War ended is reflected in the increased attention paid to nuclear weapons states in regional settings, and to ways not only to deter such states but also to assure their neighbors, (many of whom are U.S. allies, that they do not need nuclear weapons to protect their interests against regional aggressors. This study places an emphasis on how the concept of *tailored* deterrence is evolving,[12] the different mindsets of regional aggressors, controlling escalation in regional crises, the growing importance of missile defenses, and new dynamics for a concept that in the Cold War was called *extended* deterrence (which then was especially prominent for the North Atlantic Treaty Organization [NATO]) and now is referred to in policy documents as *assurance*. Planning for assurance is a major feature of the evolving security environment.[13]

Third, even before al-Qaeda launched its attack on September 11, 2001 (known to history as 9/11), U.S. policy makers were aware of the possibility that nonstate terrorists might acquire nuclear weapons or other weapons of mass destruction (WMD) and use them against the United States, its allies, or other nations. This nuclear concern was intensified exponentially after 9/11. Countering nuclear terrorism and nuclear proliferation were elevated in priority in U.S. policy, eclipsing (many would argue) the traditional nuclear deterrence missions. The committee is aware of this fact and devoted attention to understanding deterrent requirements related to counterterrorism and nonproliferation planning.

The committee did not try to probe deeply into the nuclear weapons side of the equation. That would have required special clearances and a work schedule beyond the charter of the study. However, the committee was briefed on current plans. Today's U.S. nuclear stockpile consists of two nuclear weapons types for submarine-launched ballistic missiles (SLBMs), two others for ICBMs, and three (with multiple modifications) for airborne platforms.[14] The NWC, the senior body synchronizing requirements for nuclear weapons, has approved a "3+2 Strategy," which is the "long-term strategy to move toward a stockpile consisting of only three interoperable ballistic missile warheads deployed on both the SLBM and ICBM

[12] See M. Elaine Bunn, 2007, *Can Deterrence Be Tailored?,* Washington, D.C., Institute for National Security Studies, National Defense University, January.

[13] The committee devoted much of its fact-finding to the regional dimension, reviewing literature, and receiving briefings from experts. It did not, however, have an opportunity to visit the regional combatant commands (as it did STRATCOM) to gain their perspectives on deterrence in regional settings.

[14] The current U.S. nuclear stockpile includes the W76 and W88 warheads for SLBMs, theW78 and W87 warheads for ICBMs, the B61 and B83 bombs, and the W80 warhead for air-launched cruise missiles.

legs of the triad and two air delivered warheads, (1) a gravity bomb deployable on both bombers and tactical aircraft" and (2) a warhead for a long-range stand-off (LRSO) capability ultimately to replace the air-launched cruise missiles (ALCMs).[15] Whether this strategy can be sustained with adequate funding over the long term remains to be seen.

Fourth, while this committee addressed tools, methods, and approaches appropriate to sizing the *delivery* systems, it did not extend its discussions to whether the same tools, methods, and approaches provide an analytically sound basis for determining the appropriate stockpile size and mix. Fifth and last, the committee understands that over the planned lifetime of U.S. Air Force and Navy nuclear delivery platforms and weapons, both continuity and change will be significant. Planning for continuity must also provide flexibility and options to respond to change, both geostrategic and technological, which could be very sudden and dramatic in the years ahead.

It was our great pleasure to work with the extremely dedicated and professional members of the committee during this study. We would like to single out committee members Michael Wheeler, Paul Davis, Stephen Walker, W. Peter Cherry, and Jerrold Post for their outstanding contributions as chapter leads. It is our hope that this report provides a useful service to DoD and the nation.

Gerald F. Perryman, Jr., *Co-Chair*
Allison Astorino-Courtois, *Co-Chair*
Committee on U.S. Air Force Strategic
Deterrence Military Capabilities in the
21st Century Security Environment

[15] See B61 Life Extension Program and Future Stockpile Strategy, House Armed Services Committee Subcommittee on Armed Services, testimony of Donald L. Cook, Deputy Administrator for Defense Programs, NNSA, October 30, and 2013. Those hearings addressed the increasingly costly B61 life extension program and its place in the future stockpile strategy.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Kevin P. Chilton, U.S. Air Force (retired),
Raymond Jeanloz, University of California, Berkeley,
Michael E. Kassner, University of Southern California,
Brad Roberts, Stanford University,
C. Paul Robinson, Sandia National Laboratories (emeritus),
James Scouras, Johns Hopkins University Applied Physics Laboratory,
Alan Washburn, Naval Postgraduate School, and
Larry D. Welch, Institute for Defense Analyses (emeritus).

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Stephen M. Robinson, University of Wisconsin,

Madison. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Acronyms

AFB	Air Force Base
AFGSC	Air Force Global Strike Command
AFSB	Air Force Studies Board
ALCM	air-launched cruise missile
BMD	ballistic missile defense
CAS	complex adaptive systems
COCOM	combatant command
CTBT	Comprehensive Nuclear Test Ban Treaty
DAAP	deterrence and assurance analysis program
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities
DSB	Defense Science Board
FYDP	Future Years Defense Program
IAEA	International Atomic Energy Agency
ICBM	intercontinental ballistic missile
IT	information technology

JCIDS	Joint Capabilities Integration Development System
JCS	Joint Chiefs of Staff
JROC	Joint Requirements Oversight Council
LEP	Life Extension Program
LRSO	Long-Range Standoff (Missile)
MIRV	multiple independently retargetable reentry vehicle
MM	Minuteman missile
NATO	North American Treaty Organization
NNSA	National Nuclear Security Administration
NPR	Nuclear Posture Review
NPT	Nuclear Nonproliferation Treaty
NRC	National Research Council
NSA	National Security Agency
NSC	National Security Council
NWC	Nuclear Weapons Council
OSD	Office of the Secretary of Defense
PPBE	planning, programming, budgeting, and execution
RSAS	RAND Strategy Assessment System
SAC	Strategic Air Command
SALT	Strategic Arms Limitation Treaty
SLBM	submarine-launched ballistic missile
SNA	social network analysis
START	Strategic Arms Reduction Treaty
STRATCOM	Strategic Command
TOR	terms of reference
UN	United Nations
USD/AT&L	Under Secretary of Defense (Acquisition, Technology, and Logistics)
WMD	weapons of mass destruction

Summary

The United States developed and used nuclear weapons in the Second World War and, since the surrender of Japan, has maintained a nuclear capability to deter and influence the behavior of adversaries and assure allies. Over time, geopolitical developments have transformed what started as a bipolar world order after that war, which involved the United States and the Soviet Union and their respective allies, into the current multinodal global reality, in which nonstate and state actors play an important role. Since the early 1960s, the U.S. strategic nuclear posture has been composed of a triad of nuclear-certified long-range bombers, intercontinental ballistic missiles, and submarine-launched ballistic missiles. Also, since the early 1970s, U.S. nuclear forces have been subject to strategic arms control agreements. The large numbers and diversified nature of the U.S. nonstrategic (tactical) nuclear forces, which cannot be ignored as part of the overall nuclear deterrent, have decreased substantially since the Cold War. While there is domestic consensus today on the need to maintain an effective deterrent, there is no consensus on precisely what that requires, especially in a changing geopolitical environment and with continued reductions in nuclear arms. This places a premium on having the best possible analytic tools, methods, and approaches for understanding how nuclear deterrence and assurance work, how they might fail, and how failure can be averted by U.S. nuclear forces.

In a 2013 speech following negotiations for the New Strategic Arms Reduction Treaty (entry into force: February 5, 2011), President Obama took a further step and announced that the United States had "determined that we can ensure the security of America and our allies, and maintain a strong and credible strategic deterrent, while reducing our deployed strategic nuclear weapons by up to one-third…" and that he intended to "seek negotiated cuts with Russia to move beyond Cold War nuclear postures."[1] President Obama's announcement carried with it a series of complex conceptual and analytic challenges. For example, if nuclear weapons are to take a lesser role in U.S. security strategy, what role should that be? In which circumstances is it reasonable and credible to pose a nuclear threat? At lower levels of deployed nuclear weapons, which systems and postures are essential for maintaining a strong deterrent to attack by both known and unforeseen adversaries? What should be cut, and how is this to be done without causing harm to strategic stability in multiple areas of the globe? Which nuclear capabilities, if any, are needed to assure allies of U.S. commitment to their security? Each question is made all the more challenging when considered in light of U.S. fiscal austerity, global power shifts, and other changes currently under way in the international environment.

STUDY APPROACH AND CAVEATS

While this study of the Committee on U.S. Air Force Strategic Deterrence Military Capabilities in the 21st Century Security Environment was mutually requested by the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering and the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, the results are intended to inform the Air Force research enterprise as a whole, as well as the larger audience of stakeholders involved in issues of deterrence and assurance generally and nuclear deterrence and assurance in particular. During this study of analytic tools, methods, and approaches for strategic deterrence and assurance of adversaries and allies, it became apparent that no single tool, method, or approach could address the array of deterrence and assurance challenges the Air Force and the nation will face in coming years. It also became evident that there is a critical deficit in the Air Force capacity to sustain high-quality analysis in support of its newly broadened nuclear deterrence and assurance responsibilities. Namely, the Air Force lacks a means for organizing and ensuring the training necessary to build a cadre of methodologically savvy analysts conversant in nuclear deterrence and assurance issues. Simply put, regardless of the analytic tools it possesses, the Air Force has too few people with the personal experience and rigorous analytic training required to generate the analyses necessary to determine the nuclear force structures and postures most likely to be effective deterrents. Before discussing the specific items in the terms of reference and where

[1] Executive Office of the President, Transcript of remarks by President Obama at the Brandenburg Gate, Berlin, Germany, June 14, 2013, http://www.whitehouse.gov/photos-and-video/video/2013/06/19/president-obama-speaks-people-berlin#transcript.

and how this study addresses them, the study's orientation to the issues and, thus, what is included and what is left out of this report are explained.

First, much of Cold War era deterrence theory and analysis assume a causal or nearly causal relationship between possessing massive physical power and being able to deter unfavorable actions. One of the results of this assumption has been that, until relatively recently, higher priority was given to developing tools, methods, and approaches for estimating physical effects of weapons than to the human perceptual aspects of deterrence and assurance.[2] Well-founded understanding of adversary and ally perceptions, motivations, and decision processes is a critical precondition for producing the types of analyses needed to support planning for nuclear capabilities relevant to assuring multiple actors across a variety of international circumstances. As a consequence, this study focuses on tools, methods, and approaches for understanding human behavior and does not address assessments of physical effects and capabilities.

Second, there are literally scores of analytic tools, methods, and approaches.[3] It would be neither reasonable nor useful to conduct a comprehensive review of all of them. Instead, the study leveraged the substantial expertise of the committee membership, previous reviews, and numerous briefings and discussions in workshops and committee meetings to identify a set of appropriate tools, methods, and approaches and assess their general applicability to deterrence and assurance issues, as well as the type of analytic role (e.g., data generation, decision support) for which each tool, method, and approach is best suited. Relatedly, this report does not suggest either a single or a set of silver bullets for addressing the range of issues confronting the Air Force, and nowhere does the report imply or state that computers or checklists might replace the human intellect.

Third, the report is not limited to nuclear deterrence or assurance. Of note, there do not appear to be standard definitions of basic deterrence-related concepts within the U.S. national security community. Theoretically, if not doctrinally, assurance of allies, together with deterrence of adversaries from nuclear use, or deterrence of other activities by way of nuclear threats are at the far ends of a spectrum of influence activities that concern the U.S. defense establishment. Moreover, some argue that attempting to consider nuclear deterrence in isolation from

[2] Official recognition of the importance to deterrence and assurance of understanding human decision processing and perceptions is illustrated in *Joint Publication 1-02*, which states that deterrence is "the prevention from action by fear of the consequences … a state of mind brought about by the existence of a credible threat of unacceptable counteraction;" and the 2006 *Deterrence Operations Joint Operating Concept*, where "deterrence" equates to "decisive influence over [adversaries'] decision making" by increasing the costs associated with taking an action and decreasing the rewards and costs of restraint.

[3] National Research Council, 2013, *U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment: A Workshop Summary*, The National Academies Press, Washington, D.C.

TABLE S-1 Items in the Terms of Reference (TOR) and Corresponding Recommendations

TOR Item	Response[a]
Item 1, Key Issues. Identify the broad analytic issues and factors that must be considered in seeking nuclear deterrence of adversaries and assurance of allies in the 21st century.	Key concepts, definitions, and issues presented in Chapter 2.
Item 2, Tools, Methods, and Approaches. Describe and assess tools, methods—including behavioral science-based methods—and approaches for improving the understanding of how nuclear deterrence and assurance work or may fail in the 21st century and the extent to which such failures might be averted or mitigated by the proper choice of nuclear systems, technological capabilities, postures, and concepts of operation of American nuclear forces.	Review of readily accessible analytic tools, methods, and approaches appears in Chapter 3, with an extended example in Appendix E. **Recommendation 2.** The Air Force should focus analytic enhancements in support of deterrence and assurance assessment on the human and human organizational factors at the heart of deterrence and assurance. The committee interpreted Items 2 and 3 of the TOR to mean that it should describe and assess analytic tools, methods, and approaches that would help both (1) in improving and understanding deterrence and assurance and (2) understanding how nuclear forces, posture, technological capabilities, and concepts of operations can improve prospects or mitigate failures. The committee and the Air Force understood that the study was not going to make recommendations about force structure and the like.

other deterrence considerations—to the degree that was possible during the Cold War—is increasingly difficult and likely to be shortsighted in the current security environment.

METHODOLOGY FOR RESPONDING TO THE TERMS OF REFERENCE

The recommendations discussed in this section are organized as they relate to the five items in the terms of reference (TOR). Briefly, these are (1) to identify key issues in 21st century deterrence and assurance analysis; (2) describe and assess analytic tools, methods, and approaches; (3) discuss how the Air Force could respond to deterrence and assurance needs, including suggesting an analytic framework; (4) suggest how the Air Force might evaluate and validate new tools, methods, and approaches; and (5) recommend specific classes of tools, methods, and approaches. All of the TOR are listed in the left-hand column of Table S-1.[4] How and where each item of the TOR is addressed in the report are described in

[4] Appendix A also provides the TOR.

TABLE S-1 Continued

TOR Item	Response[a]
Item 3, Framework. Discuss the implications for the Air Force and how it could best respond to these deterrence and assurance needs. Include in this discussion a framework for identifying the risks and benefits associated with different nuclear force postures, structures, levels, and concepts of operation.	A high-level deterrence and assurance task framework is presented in Chapter 4. **Recommendation 1.** In support of senior Air Force leadership guidance, including the *Flight Plan for the Air Force Nuclear Enterprise*,[b] the Air Force should develop and maintain a comprehensive strategic deterrence analysis plan to identify the tasks that produce information required to organize, equip, and train Air Force nuclear deterrence and assurance forces and support combatant commanders. **Recommendation 2.** The Air Force should focus analytic enhancements in support of deterrence and assurance assessment on the human and human organizational factors at the heart of deterrence and assurance. **Recommendation 3.** The Air Force, working with its Service partners and the Department of Defense more generally, should pursue research on deterrence and assurance with a coherent approach that involves content analysis, leadership profiling, abstract modeling, and gaming and simulations as a suite of methods. It should organize its investments in analytic and other activities accordingly. **Recommendation 4.** The Air Force analytic community should pursue methods of understanding and incorporating the concept of deep uncertainty. The committee interpreted Items 2 and 3 of the TOR to mean that it should describe and assess analytic tools, methods, and approaches that would help both (1) in improving and understanding deterrence and assurance; and (2) in helping to understand how nuclear forces, posture, technological capabilities, and concepts of operations can improve prospects or mitigate failures. The committee and the Air Force understood that the study was not going to make recommendations about force structure and the like.
Item 4, Evaluation. Recommend criteria and a framework for validating the tools, methods, and approaches and for identifying those most promising for Air Force usage.	Readily accessible analytic approaches and methods are reviewed in Chapter 3, with an extended example in Appendix E.

Continued

TABLE S-1 Continued

TOR Item	Response[a]
Item 5, Tools. Recommend an appropriate mix of the classes of analytical tools affordable in today's austere financial climate and identify what can be planned for by the Air Force as future improvements to this mix if and should defense budgets increase or decrease.	The choice of the *appropriate* analytic method or approach is fully dependent on the type of analytic question posed; the data and time available for analysis; and the quality of results desired. Beyond what was presented in *Concepts and Analysis of Nuclear Strategy Framework Report*, there is no way to correctly recommend specific approaches or tools without these details.[c] **Recommendation 5.** Air Force analysis supporting nuclear deterrence and assurance issues should draw from a suite of appropriate methods, including hybrid methods that combine and integrate different methods. **Recommendation 6.** The Air Force should maintain its cadre of career analytic professionals (both civilian and military) with expertise in nuclear deterrence and assurance strategy to improve Air Force support to Combatant Commanders' planning and operations, since methods can inform, but never replace, the judgment of expert analysts. This could be facilitated by specific treatment of analysts in Vector 5 of the *Flight Plan for the Air Force Nuclear Enterprise*.[b]

[a] Chapter 4 provides suggestions for Air Force organizations that would have roles in implementing the report's recommendations.
[b] Air Force, 2013, *Flight Plan for the Air Force Nuclear Enterprise,* Washington, D.C.
The TOR are contained in Appendix A.
[c] B. Bragg, ed., 2011, *Concepts and Analysis of Nuclear Strategy Framework Report,* prepared by NSI, Inc., for the Strategic Multilayer Assessment Office, Department of Defense, http://nsiteam.com/publications/.

the right-hand column of Table S-1 and discussed in more detail in the next section. Supplemented by the discussions and examples provided in Chapters 2 and 3 and supporting appendixes, the individual recommendations should be read as aspects of an overarching theme of the report, which is the need for the Air Force to refocus and sustain its intellectual capital in the areas of deterrence and assurance in general and political understanding of nuclear issues in particular. Table S-2 provides a complete list of report observations, findings, and recommendations mapped against the TOR.

TABLE S-2 Complete List of Observations, Findings, and Recommendations

Terms of Reference Item	Observation, Finding, Recommendation
Item 1, Key Issues. Identify the broad analytic issues and factors that must be considered in seeking nuclear deterrence of adversaries and assurance of allies in the 21st Century.	Observation 2-1 (Norms of Behavior), p. 35 Finding 2-1 (Deep Uncertainty), p. 38 Observation 2-2 (Missile Defense), p. 40 Observation 2-3 (Extended Deterrence), p. 41 Observation 2-4 (Dissuasion by Denial), p. 41 Finding 2-2 (Analytic Framework), p. 46
Item 2, Tools, Methods, and Approaches. Describe and assess tools, methods—including behavioral science-based methods—and approaches for improving the understanding of how nuclear deterrence and assurance work or may fail in the 21st century and the extent to which such failures might be averted or mitigated by the proper choice of nuclear systems, technological capabilities, postures, and concepts of operation of American nuclear forces.	Observation 3-1 (Building Air Force Subject Matter Expertise), p. 52 Finding 3-1 (Long-Term Career Development), p. 52 Observation 3-2 (Effective War-Gaming), p. 62 Finding 3-2 (Psychological Framework), p. 65 Finding 3-3 (Tailoring Key Messages), p. 66 Observation 3-3 (Alternative Adversary Models), p. 74 Observation 3-4 (Modeling and Limited Rationality), p. 76 Finding 3-4 (Tailored Deterrence), p. 78 Observation 3-5 (Fostering Cross-Domain Collaboration), p. 83 Recommendation 2 (Actor and Multiactor Modeling), p. 93
Item 3, Framework. Discuss the implications for the Air Force and how it could best respond to these deterrence and assurance needs. Include in this discussion a framework for identifying the risks and benefits associated with different nuclear force postures, structures, levels, and concepts of operation.	Finding 2-2 (Analytic Framework), p. 46 Recommendation 1 (Analysis Plan), p. 92 Finding 3-2 (Psychological Framework), p. 65 Finding 3-3 (Tailoring Key Messages), p. 66 Recommendation 2 (Actor and Multiactor Modeling), p. 93 Finding 3-4 (Tailored Deterrence), p. 78 Recommendation 3 (Research), p. 94 Finding 2-1 (Deep Uncertainty), p. 38 Recommendation 4 (Deep Uncertainty), p. 96
Item 4, Evaluation. Recommend criteria and a framework for validating the tools, methods, and approaches and for identifying those most promising for Air Force usage.	Observation 3-1 (Building Air Force Subject Matter Expertise), p. 52 Finding 3-1 (Long-Term Career Development), p. 52 Observation 3-2 (Effective War-Gaming), p. 62 Finding 3-2 (Psychological Framework), p. 65 Finding 3-3 (Tailoring Key Messages), p. 66 Observation 3-3 (Alternative Adversary Models), p. 74 Observation 3-4 (Modeling and Limited Rationality), p. 76 Finding 3-4 (Tailored Deterrence), p. 78 Observation 3-5 (Fostering Cross-Domain Collaboration), p. 83 Recommendation 2 (Actor and Multiactor Modeling), p. 93

Continued

TABLE S-2 Continued

Terms of Reference Item	Observation, Finding, Recommendation
Item 5, Tools. Recommend an appropriate mix of the classes of analytical tools affordable in today's austere financial climate and identify what can be planned for by the Air Force as future improvements to this mix if and should defense budgets increase or decrease.	Finding 3-4 (Tailored Deterrence), p. 78 Recommendation 5 (Methods), p. 96 Finding 3-1 (Long-Term Career Development), p. 52 Recommendation 6 (Analysts), p. 97

Key Issues in 21st Century Deterrence and Assurance Analysis

Item 1 of the terms of reference was addressed by extensive committee debate and by input from subject matter expert speakers in a variety of disciplines, ranging from the new and eclectic, such as *neurodeterrence,* which combines advances in neurobiology and study of deterrence and threat behaviors, to more familiar political and technical experts with decades of experience in arms control and management of the nuclear enterprise. The "broad analytic issues and factors" gleaned from these sessions appear throughout Chapter 2, which suggests and discusses three broad categories into which recommended themes fall (see Table S-3). Chapter 2 also lays out "stressful questions" associated with peer, near-peer, regional, and nonstate challenges, as well as important deterrence and assurance issues like nuclear command and control, force modernization, air and missile defense, and geostrategic and technological changes not directly addressed in this study.

Description and Assessment of Analytic Tools, Methods, and Approaches

The first component of Item 2 of the terms of reference—assessing tools, methods and approaches—was addressed in light of the issues identified in Chapter 2 as critical to 21st century deterrence and assurance analysis. A summary of reviewed methods and tools appears in Chapter 3 with further illustration in Appendixes D and E. Given the time limitation of this study, the second element of this item was not addressed. Understanding the psychological mechanisms that govern what deters and what assures are preconditions for assessment of the attributes of various nuclear systems, technological capabilities, postures, and concepts of operation of U.S. nuclear forces. Consequently, improving the Air Force's capacity to account for and use the types of actor- and decision-unit-specific information needed to tailor deterrence and assurance messages and activities is a necessary requirement.

TABLE S-3 Focus Issues

Category	Theme
Understanding deterrence and influence in modern contexts	Increased importance of general deterrence and cumulative deterrence. The need to move beyond strict rational-actor assumptions. More complex regional and escalatory dynamics. The role of dissuasion by denial.
Planning and analysis	Dealing with expanded uncertainty. The relationship between defense and assurance. Anticipating the unexpected, geopolitically and technologically.
Attending to basics	Maintaining safe, secure, and effective forces.

Doing so will allow the Air Force to better calculate the specific regional capabilities it will need to provide to allow maximum flexibility to identify and influence activities likely to be most effective in present conditions and those it may face in the future. In addition, improved understanding of the human factors involved in deterrence and assurance situations may facilitate earlier recognition of potential deterrence or assurance failures.

The Air Force needs to plan now to contribute the capabilities required to deter and assure decades into the future. Further, the Air Force would be the obvious advocate for a U.S.-government-wide program to develop systematic, multidisciplinary *generalized* leadership and decision-making constructs and models to improve the robustness of that planning by anticipating the range of potential behaviors, consequences, and situations that may be faced. This will also provide a baseline set of regional deterrence and assurance environments that could help analysts assert how current and future leadership changes might affect the deterrence and assurance environment. Finally, the Air Force would ideally explore the notion of "deep uncertainty" in planning support analyses in order to expand analysts' awareness of future uncertainties and the types of circumstances most prone to significant unintended consequences. [5]

[5] Deep uncertainty refers to "materially important uncertainties that cannot be adequately treated as simple random processes and that cannot realistically be resolved at the time they come into play" (Paul K. Davis and James P. Kahan, 2007, *Theory and Methods for Supporting High Level Military Decisionmaking,* RAND Corp., Santa Monica, Calif., http://www.rand.org/pubs/technical_reports/TR422.html, p. 6).

Suggested Analytic Framework for Air Force Deterrence and Assurance Needs

A high-level deterrence and assurance task framework is presented in Chapter 4. Awareness of the web of complexities involved in managing the multitude of overlapping deterrence and assurance issues led the formulation of Recommendation 1. Namely, that the Air Force design and pursue a coordinated deterrence and assurance analysis program—something that does not currently exist—to guide its efforts. Recommendations 2, 3, and 4 refer to some of the attributes that a deterrence and assurance analysis program should have. In addition, the program might include tracks to refine and apply the psychologically based concepts at the heart of deterrence and assurance; to encourage practitioner-academic dialog to facilitate practitioner access to academic strategic studies on the one hand and educate academics on operational priorities and constraints in the military setting on the other; to institutionalize and integrate ongoing efforts across the Air Force, including the Air Force Global Strike Command, the Strategic Command (STRATCOM), and elsewhere; and, finally, to train a cadre of deterrence and assurance analysts conversant in multiple analytic methods and approaches.[6]

Such a program would benefit the Air Force directly by providing a guide for developing the types of robust analyses currently lacking, but necessary to underpin and defend Air Force capabilities. The recommended deterrence and assurance analysis program would also provide the means for coordinating and monitoring analytic projects across the Air Force, limiting both (1) costs associated with duplicate independent efforts and (2) overreliance on traditional deterrence metrics—for example, damage expectancies and comparative weapons counting, which are less relevant in the current security environment.

Air Force decision makers, analysts, and, most critically, consumers of deterrence and assurance analyses may also consider adopting the habit of considering the limitations and appropriate uses of any analytic tool, method, and approach, along with the results such use might generate. Like hammers, saws, and other carpenter's tools, analytic methods have appropriate and inappropriate uses according to the nature of the task to which they are put. As with using hand tools to build a table, well-executed analysis of issues of human perception and behavior require integrated use of multiple methods and tools to produce robust and defensible results. Using tools properly and in tandem can significantly improve analytic breadth, accuracy, and insight. As such, the approach to deterrence and assurance analysis adopted by the Air Force would ideally include as a specific goal

[6] Officials at STRATCOM discussed their general awareness of efforts to reinvigorate deterrence thought and develop deterrence experts, including educational courses offered at the Air Force Nuclear Weapons Center, establishment of a Deterrence and Assurance Working Group, and a proposed nuclear fellows program.

the careful integration of analytic techniques. Combining methods in a planned and coordinated way can also help refine analyses over time.[7]

Methods for Air Force Evaluation and Validation of Tools, Methods, and Approaches

Rather than propose a static set of deterrence and assurance tools, the report identifies factors that might be used to guide a multiyear, multimethod research agenda. [8] Moreover, the task of providing a framework for "validating" tools became both less relevant and exponentially more complex with the report's focus on tools, methods, and approaches tied to better understanding of the impact of perceptual factors as opposed to capability factors on deterrence and assurance.[9] Where human behavior is the subject of concern, there are two types of validity that must be tested: internal and external. Internal validity refers to the internal logic of the model and the degree of confidence that it actually taps into and explains the underlying construct that the researcher intends—for example, the psychological mechanisms that account for decisions to forego benefits in light of costs and thus be deterred from taking an action. Implicit in this is that the model is a comprehensive representation of that construct. External validity refers to the degree to which a model or tool is applicable beyond the particular circumstance for which it was built—for example, whether a model explaining Russian decision making would also apply to China. The means of validity testing, or validation, however, vary according to the specific tool, method, or approach used. Thus, while

[7] Integrating analytic methods need not be a costly or onerous undertaking in order to produce valuable results. In many cases, the output of one approach fits perfectly into or can help frame the required input of another. For example, social network analysis can identify key decision makers who should be subject to leadership profiling and other decision analyses. Hypotheses regarding the strategic interactions of regional adversaries derived from game theoretic analysis and case studies can be further tested in series of human (war) games, and so on. Table 3-1 in Chapter 3 illustrates the general mixes of the methods reviewed for this study. For a thorough discussion of integrating multiple analytic techniques for deterrence analysis, see Office of the Secretary of Defense Multi-layer Analysis Deterrence Subgroup A Report: Deterrence-Supporting Approaches and Comparative Analysis and Integration Recommendations, June 30, 2009.

[8] It should be noted, however, that a nuclear force posture comparison modeling project undertaken by STRATCOM (J5) for the 2010 Nuclear Posture Review may serve as the core of a development project in this area.

[9] It is important to note that, although the words used are often the same, tools, methods, and approaches for issues of human behavior are subject to different notions of what constitutes a model and tool "validation" than is typical in engineering and other scientific disciplines. These concepts can also be different from what analysts often mean by "validation." For example, How well has the model performed in the past? or How much confidence should I have in what it tells me? are often what analysts (as opposed to model builders) mean when they refer to "validating" an analytic model, framework, or tool.

no general framework for validation is suggested in this report, where appropriate, these issues are treated in the reviews of methods presented in Chapter 3 and Appendixes D and E.

Recommending Specific Classes of Tools, Methods, and Approaches

As noted above, the number and variety of analytic tools, methods, and approaches is enormous. Each of those reviewed for this report is relatively mature and accessible to the Air Force, if not directly to analysts, then via experts and companies that can easily be found to apply them. The complexity of planning and analysis for nuclear deterrence and assurance that will confront current and subsequent generations is likely to continue to increase exponentially. Paradoxically, rapid advances in communications technologies means that conveying deterrence and assurance messages will become increasingly difficult to control as counter-communications are easier to issue and perceived U.S. intentions become subject to literally global interpretation. The relative lack of exposure of many of today's analysts to nuclear-related issues may make it premature for the Air Force to consider significant investment in classes of tools, methods, and approaches and certainly, in particular, in tools needed to conduct deterrence analyses now and into the future. Instead, the Air Force would do well to focus on its people first. This will ensure that Air Force personnel are able to provide the most credible and analytically based perspectives in both Air Force and joint decision fora, and that the Air Force is able to provide leaders with informed and reliable reviews and critiques of alternative force structures, sizing, and deployment options.

1

Introduction

THE EVOLVING 21ST CENTURY SECURITY ENVIRONMENT

Path to the Present

On June 14, 2013, President Obama spoke in Berlin. He used the occasion to announce the completion of a two-year review of American nuclear weapons policy and his related decisions on the next steps in nuclear arms control. Some 75 years before the President's Berlin speech, two German scientists, working in a laboratory in the suburbs of a Berlin not far from where he spoke, achieved nuclear fission. That passage of time (75 years) suggests one time frame appropriate for thinking about the security environment. Although not easily adapted to security planning, a 75-year horizon does begin to approach the life spans of major strategic weapons systems such as the B-52 bomber and the Minuteman (MM) III missile.[1] In the future as in the past, however, rapid political, economic, and technological change may alter priorities in national and thus in Air Force deterrence considerations.

During a period of extreme national emergency in the middle of the 20th century, the United States partnered with its British allies in a secret, expensive, risky, and urgent project, which created the world's first nuclear weapon. By the time the bomb was available in 1945, Germany had surrendered but Japan was

[1] The B-52H and MM III have been in the force since the 1960s. They of course have been refurbished and modified over time to extend their lives and/or improve their performance, a process that continues today. It is thought that they can be sustained until about 2030 (and perhaps beyond, if necessary).

still at war. The United States used the bomb with the intent to shock Japan into surrendering sooner rather than later so as to avoid the need for an invasion of the Japanese main islands.[2]

During a brief postwar interregnum, the United States proposed the Baruch Plan to place nuclear weapons under international control. The plan failed as the Cold War set in. For the next quarter century, the world was caught in a largely bipolar power struggle, with nuclear weapons at the heart of the competition. The evolution of American deterrent strategy (and its supporting concepts) reflected that reality.[3]

In waging the Cold War, the United States developed a large nuclear enterprise to design, test, and produce nuclear weapons. At its peak in the mid-1960s, the U.S. nuclear stockpile rose to over 31,000 weapons, including deployed and nondeployed weapons.[4] Strategic weapons were deployed briefly on a quadrad of delivery systems, which included intercontinental-range cruise missiles,[5] and then on a triad of long-range bombers,[6] intercontinental ballistic missiles (ICBMs),[7]

[2] Although there is scholarly debate about how to weigh the different factors that led to Japan's surrender, the decision came rapidly after the deployment of nuclear weapons. The first atomic bomb was dropped on Hiroshima on August 6, 1945. A second bomb was used on Nagasaki three days later. Hostilities ceased on August 14, 1945, followed by Japan's unconditional surrender.

[3] There were a succession of presidential guidance documents issued during the nine American administrations that governed the evolution of Cold War American deterrence planning: National Security Council (NSC) papers NSC-68 (1950), NSC 162/2 (1953), and NSC 5906/1 (1959), National Security Decision Memorandum 242 (1974), Presidential Directive 59 (1980), and National Security Decision Directive 13 (1981). Academics tend to look at the surface of change, using phrases like massive retaliation, flexible response, and mutual assured destruction. Those are phrases grounded in the realities of the time (and especially the desire of new administrations to distinguish their policies from those of their predecessors), but they tend to oversimplify the evolution of American nuclear deterrence policy by suggesting sharp divides, where in fact there was a more gradual evolution and considerable continuity. For instance, the Eisenhower administration already was moving toward flexible response by the time NSC 5906/1 was issued in 1959, and the Kennedy administration kept NSC 5906/1 as policy until it was rescinded in 1963, toward the end of Kennedy's presidency. In practice, the classified documents often codified changes that already were under way in American policy and strategy. Those changes are reflected in official speeches, news releases, internal memoranda, and the like.

[4] Department of Defense (DoD), 2010, *Fact Sheet: Increasing Transparency in the U.S. Nuclear Weapons Stockpile,* Washington, D.C., May 3.

[5] The early intercontinental cruise missile, the SNARK, went on alert in March 1960. It was retired soon after its initial deployment but not before the *USS George Washington* Polaris missile submarine left on its inaugural deterrent patrol in November 1960.

[6] Strategic Air Command (SAC) bombers initially were not on continuous 24-hour (24/7) alert. From November 1956 to June 1957, SAC began experimenting with the practice of keeping bombers and tankers on continuous 24-hour alert. The experiments showed that ground alert was feasible, and a large percentage of the SAC bomber force went on routine day-to-day alert in late 1957. They continued this practice throughout the Cold War, and for 8 years, during the crisis atmosphere of the 1960s, a part of the bomber force also was on 24/7 airborne nuclear alert.

[7] The first U.S. ICBM, an Atlas missile, went on alert in October 1959.

and submarine-launched ballistic missiles launched from nuclear-powered submarines.[8] The United States also deployed a wide variety of so-called "tactical" nuclear weapons at sea (for land, sea, and undersea warfare), with Army missile and tube artillery units and special operations groups, on ground-based Air Force aircraft, and on missiles designed for air and ballistic missile defense.[9] The United States also extended a nuclear umbrella to allies.[10] It pursued nuclear arms control regimes, which sought to stabilize the bipolar competition with the Soviet Union,[11] to constrain (and, where possible, prevent and roll back) nuclear proliferation while allowing the pursuit of peaceful applications of nuclear energy,[12] and to protect the environment.[13] And notwithstanding the speculation of some early nuclear

[8] The first U.S. fleet ballistic missile submarine, the *USS George Washington,* deployed on its first operational patrol in November 1960. Earlier, the Navy had a submarine equipped with a nuclear-armed cruise missile, the Regulus, which had a relatively short range (less than 1,000 km) and could only be launched while the submarine was surfaced.

[9] The United States developed and deployed a large variety of tactical nuclear weapons for a variety of platforms: aircraft, artillery, missiles of various ranges, torpedoes, mines, and so forth. See Amy F. Woolf, 2012, *Nonstrategic Nuclear Weapons,* Congressional Research Service, Washington, D.C., December 19.

[10] In 1949 the United States was a founding member of the North Atlantic Treaty Organization (NATO). U.S. nuclear forces were a vital part of NATO planning from its inception. The first NATO strategy-planning document, Standing Group 1, was circulated to the allied chiefs of staff for comment in early October 1949. It assumed that U.S. nuclear weapons would be used at the outset of any NATO war with the Soviet Union.

[11] During the Cold War, the United States negotiated a network of bilateral nuclear arms agreements with the Soviet Union. In 1972, the United States completed the Strategic Arms Limitation Treaty (SALT) I talks, resulting in an interim agreement on offensive strategic arms and the Anti-Ballistic Missile Treaty; the interim agreement was followed by SALT II (signed in 1979 and observed until 1986, although never ratified); Intermediate Nuclear Forces (signed in 1987 and still in force); and the Strategic Arms Reduction Treaty, START I (signed in 1991 before the Soviet Union collapsed and brought into force following the Lisbon Protocols of 1992). Following the Cold War, the United States negotiated START II, which was signed in January 1993 and repudiated by the Russian Federation when the United States unilaterally withdrew from the Anti-Ballistic Missile Treaty in 2002, roughly coincident with negotiating the Treaty of Moscow (which used START I verification provisions). The Obama administration entered office shortly before START I expired. The New START treaty was signed in 2010 and entered into force the following year.

[12] President Eisenhower's Atoms for Peace speech to the United Nations in December 1953 led to the creation a few years later of the International Atomic Energy Agency (IAEA). In 1965, President Johnson made the decision that the United States would make it a top priority to pursue a Nuclear Non-Proliferation Treaty (NPT). By 1968, the NPT was signed, although its entry into force was delayed until 1970 because of the political environment following Russia's invasion of Czechoslovakia. The NPT was extended indefinitely in 1995 and remains in force today, although some believe its future is problematic if a new wave of proliferation begins.

[13] In 1954, an American thermonuclear test contaminated a Japanese fishing trawler, helping spark a worldwide movement seeking the end of nuclear testing. The United States entered into nuclear testing talks with Russia and Britain in 1958. The talks cut across security and environmental issues

strategists that the awesome power of nuclear weapons merely by their existence made major war obsolete, the United States fought major regional conventional wars (Korea, Vietnam) where nuclear weapons cast a shadow over but were not employed in the conflicts.

The Berlin Wall fell in 1989, and by the end of 1991, the Soviet Union had dissolved. Although there were residual actions required to record the transition (including the question of who would inherit the Soviet Union's nuclear weapons), for all practical purposes the Cold War was over.

The above discussion presents an incomplete picture of a complex environment over the almost 50 years within which U.S. nuclear weapons policy and strategy evolved during the Cold War. Another potential time span for the committee's deliberations is 25 years (roughly the time that has passed since the end of the Cold War), which, for purposes of deterrence and assurances, spanned a radically different geopolitical world.

As the Cold War was ending, another nuclear era was unfolding. In August 1990, Iraq invaded Kuwait. The United States assembled a coalition to reverse Iraq's aggression, and following the First Gulf War, helped organize an international inspection regime to dismantle Iraq's weapons of mass destruction (WMD). The new inspection regime revealed how far Iraq had advanced toward developing a nuclear weapons program, covertly and behind the veil of seemingly legitimate nuclear activities subject to then-routine IAEA inspections. Coinciding as it did with the end of the Cold War, this revelation helped shift U.S. attention toward regional aggression and the dangers posed by nuclear weapons proliferating into the hands of leaders like Saddam Hussein.[14]

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and also came to be seen as a mean of restraining further proliferation. Formal agreements followed: the Limited Test Ban Treaty (1963); the Threshold Test Ban Treaty (1974), and the Peaceful Nuclear Explosions Treaty (1976), which were observed but did not come into force until the negotiation of verification protocols in 1990. At the transition from the Cold War, Congress first imposed a moratorium on further American nuclear testing (Hatfield-Exon-Mitchell Amendment, 1992), and the Clinton administration then championed Comprehensive Nuclear Test Ban Treaty (CTBT) talks, which began in 1994 and resulted in opening a treaty for signature in 1996. The United States was the first to sign, but in October 1999, the Senate rejected the treaty. The CTBT regime remains on the books and, arguably, has created new norms, but it has yet to formally enter into force.

[14] For the Air Force, the First Gulf War and the subsequent enforcement of the no-fly zone in Iraq led to a cycle of continuous wartime footing and expeditionary operations that characterized the 1990s and beyond. As for Iraqi WMD, they of course figured prominently in the controversial U.S. decision in 2003 to intervene militarily in Iraq.

That shift was reflected in American nuclear policy and priorities for deterrence and assurance.[15] It coincided with a decade of relative American prosperity, with the explosive development of new technologies for military application (e.g., information, precision strike) and with a new age of globalization. Washington championed the development of "net-centric" military operations, which many, but not all, believed had radically transformed warfare. This was an era of U.S. strategic euphoria. It was, some have argued, our unipolar moment in history. It also was a decade when China continued its slow, steady growth.

The United States' strategic euphoria was shattered on September 11, 2001, when a small group of al-Qaeda terrorists married crude technologies (box cutters) with modern high-technology devices (four fuel-laden jet passenger aircraft) to destroy the World Trade Center, strike and severely damage the Pentagon, and come close to attacking another iconic and high-value target in Washington, D.C. (some speculate it was the White House, others the Capitol). In a matter of hours, security policy shifted radically. Countering nonstate terrorism became the highest near-term priority, with ramifications that continue today.

The United States reorganized its institutions, reoriented its military operations, and went to war, first in Afghanistan, then in Iraq, and globally against al-Qaeda and its affiliates. The threat of nonstate terrorists acquiring and using a nuclear weapon dominated Washington's strategic concerns and coincided with a focus on homeland security and on regional (vice global) problems. Fears that Iraq was reconstituting its nuclear program, and nuclear proliferation in North Korea,[16]

[15] President William Jefferson Clinton took office in 1993 as the first post-Cold War American president. Proliferation of WMD to rogue states became a priority for his administration. In December 1993, in a speech at the National Academy of Sciences, Secretary of Defense Les Aspin announced a counterproliferation initiative that joined nonproliferation as a U.S. strategy. Counterproliferation concerns quickly were reflected in a new emphasis on ballistic missile defenses to counter the missile programs of the regional rogues.

[16] North Korea (formally known as the Democratic Peoples' Republic of Korea, or DPRK) lost confidence in its Cold War patron when, in September 1990, the Soviet Union announced it would establish diplomatic relations with South Korea (the Republic of Korea, or ROK). The end of the Cold War turned North Korea's world upside down. In 1991, a North–South denuclearization agreement was concluded between the two Koreas along with a North–South reconciliation agreement. Both Koreas were admitted to the United Nations (UN) in 1992, and North Korea established diplomatic relations with South Korea. In the context of continuing insecurity and negotiating tactics, North Korea continued to pursue its nuclear weapons and missile programs, and a complicated web of regional negotiations began. In 1993, North Korea announced it was withdrawing from the NPT. This led to a re-energized American initiative that resulted in the Agreed Framework, which was signed in 1994, but which would collapse in 2002. In October 2006, North Korea conducted its first nuclear test. It remains U.S. policy to roll back the North Korean nuclear program, but there is considerable uncertainty whether that can ever succeed. This has placed a premium on U.S. security assurances to North Korea's neighbors, Japan and South Korea, and on ways to make those assurances credible.

in South Asia,[17] and in Iran,[18] became major concerns. Meanwhile, China continued its steady growth, and Russian policy took a sharp turn after 2000 under the leadership of Vladimir Putin toward a more confrontational approach to the West.

This was the world inherited by President Obama when he took office in January 2009, in the midst of a major global economic crisis. Within weeks of taking office, in a speech in Prague in April 2009, the President unveiled an ambitious agenda to reduce nuclear weapons. The new agenda was greeted with great enthusiasm in many parts of the world and contributed to President Obama receiving the Nobel Peace Prize later in the year.

The Prague speech was followed by other actions, including a new national security strategy (2010), a range of new accompanying strategy documents in the Pentagon,[19] a New START treaty (signed and ratified in 2010), a new Nuclear Posture Review (2010), and a new strategy for modernizing the nuclear stockpile

[17] In 1974, 10 years after the first Chinese nuclear test, India conducted what it called at the time a peaceful nuclear explosion (essentially, an underground test). China and India had fought a brief but intensive border war in 1962 and had major unresolved border problems. India's neighbor, Pakistan, began its own covert nuclear weapons program, which gained notoriety not only because of regional implications but also because of the covert nuclear trafficking network established by the Pakistani scientist A. Q. Khan. In 1998, India and Pakistan both conducted nuclear weapons tests, which they announced to the world. The nuclear arms race between these two rivals is a continuing source of concern, as are such possibilities as political change in Pakistan that could bring a radical Islamic government to power and Pakistan's security arrangements with Saudi Arabia (some speculate that if Iran goes nuclear, Saudi Arabia will get nuclear weapons from Pakistan).

[18] The United States has a complicated political relationship with Iran, dating to the Second World War. In 1953 the United States supported a coup that kept the Shah in power, and in 1957, it began helping the Shah develop a nuclear program for peaceful purposes under the Atoms for Peace framework and IAEA inspections. Iran signed the NPT in 1968 and ratified it 2 years later. In 1979, the Shah was overthrown and an Islamic government was established in Iran. Relations with the United States deteriorated sharply when Iran seized U.S. diplomats twice in the same year, the second time holding them hostage for over a year. Iran fought a bloody war with Iraq from 1980 to 1988, which included massive missile attacks on Iranian cities and Iraqi use of chemical weapons against Iran, which the international community tolerated. In 2002, an Iranian dissident group revealed the existence of secret nuclear facilities under construction in Iran. Iran has maintained that its program is exclusively peaceful. That is disputed by much of the international community. The United States has orchestrated a complicated diplomacy of sanctions and talks, to try to resolve the Iranian challenge while keeping the option of military action against Iran open. Israel, which took unilateral action against the Iraqi nuclear program with its strike on the Osirik reactor in 1981, watches the situation warily, as does Saudi Arabia, where there have been statements that if Iran goes nuclear, Saudi Arabia will as well. This committee devoted a considerable time to trying to understand better the Iranian challenge and its implications for this study.

[19] The National Security Strategy guides preparation of the Defense Secretary's National Defense Strategy and its associated Quadrennial Defense Review and of the Chairman of the Joint Chiefs of Staff's National Military Strategy. For discussion of these reports, and their basis in legislation, see C. Dale, 2013, *National Security Strategy: Mandates, Execution to Date, and Issues for Congress,* Congressional Research Service, Washington, D.C.

(2012). This provides the contextual prologue to President Obama's speech in Berlin in June 2013.

The President's Berlin speech and a nine-page report on the nuclear employment strategy of the United States, which was released in Washington to coincide with the Berlin speech, reaffirmed the key objectives of the 2010 Nuclear Posture Review (NPR) and their implicit prioritization. One of the decisions especially relevant to this study was to maintain a nuclear triad and to support continued NATO deployments.

Issues Moving Forward

This study acknowledges the policymakers' expectation that U.S. nuclear forces will continue to be important in both security matters and international relations. In the words of the NPR,

> As long as nuclear weapons exist, the United States must sustain a safe, secure, and effective nuclear arsenal—to maintain strategic stability with other major nuclear powers, deter potential adversaries, and reassure our allies and partners of our security commitments to them.[20]

The administration also has made clear that the United States will continue seeking to "reduce the role of nuclear weapons in deterring nonnuclear attacks," consistent with its security assurances to others and with continued efforts at negotiating further numerical reductions in nuclear arsenals. [21]

Looking forward, this study takes note of what has changed that affects deterrence and assurances, and the analytic approaches needed to support sound deterrence and assurance choices. The principles of deterrence and assurance have not changed, but other factors have.

First, the international context has changed and continues to change. The committee looked at many factors, but found several compelling in their importance for understanding deterrence requirements. There are more states that either are nuclear armed or that could become nuclear armed if they chose. Nonstate terrorists seeking nuclear weapons are a reality. Conventional weapons are vastly more precise than before. Modern warfare is changed by the overlapping effects of conventional, chemical, biological, nuclear, cyber, and space capabilities. And the balance of power between the United States, Russia, and China is shifting constantly. Added to all this is the potential for multiparty conflicts, including conflicts among regional nuclear actors other than the United States.

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[20] Department of Defense, 2010, *Nuclear Posture Review,* Washington, D.C.

[21] Ibid.

Second, while the need for a U.S. nuclear force capable of deterring Russia and China from executing an existential attack on the U.S. homeland remains, the possibility of regional crises escalating to the use of (or threatened use of) theater nuclear weapons has increased. The latter possibility demands increased examination by U.S. military planners and political leaders.

Finally, the fiscal environment in which the United States moves to sustain an effective nuclear deterrent is currently daunting, even though U.S. nuclear forces have been reduced to a small fraction of the defense budget.[22] During the Cold War, the nuclear deterrence capabilities acquired by the United States constituted a defensible and sound investment to overcompensate, given the vast and inevitable uncertainties about adversary nuclear intentions and capabilities. In recent decades, U.S. nuclear forces have been a lower priority for national leaders, and analysis and investment in nuclear deterrence have declined. Major programmatic decisions have been postponed and options reduced. The United States does not have the luxury of robustly and redundantly hedging against an uncertain nuclear future. Resources are constrained. This suggests that the analytic framework the United States needs to sustain 21st century deterrence needs to be richer and more refined than ever before.

Capabilities are important, force levels matter, and the increasing costs of nuclear systems cannot be ignored, but difficult decisions can be made better through sound analysis.

ORGANIZATION OF THE REPORT

The remainder of the report is structured as follows. Chapter 2 defines concepts, raises issues, poses problems, and indicates the themes that those involved in assessing U.S. deterrence and assurance issues need to consider. The discussion makes clear just how complex the challenges are but ultimately converges

[22] The fiscal environment for beginning and carrying through an expensive modernization program for U.S. nuclear forces remains highly uncertain. Budget battles between Congress and the administration often force DoD to cut funds from modernization accounts in order to fund operations and maintenance, in effect trading future capabilities for near-term readiness. This is happening at a time when almost all nuclear delivery systems and the weapons they carry must be modernized or replaced over the next two decades. For background, the committee consulted the following: Congressional Budget Office, 2013, *Projected Costs of U.S. Nuclear Forces: 2014 to 2023,* Washington, D.C.; J.B. Wolfsthal, J. Lewis, and M. Quint, 2014, *The Trillion Dollar Nuclear Triad: US Strategic Nuclear Modernization Over the Next Thirty Years,* James Martin Center for Nonproliferation Studies, Monterey, Calif.; and T. Harison, 2013, *Chaos and Uncertainty: The FY2014 Defense Budget and Beyond,* Center for Strategic and Budgetary Analysis, Washington, D.C.

on suggested directions. Chapter 3 discusses specific analytic tools, methods, and approaches for deterrence and assurance and points to the need to view these as a collection—that is, as a tool suite—to support analysis plans. Finally, Chapter 4 provides the complete sets recommendations, along with supporting findings and associated rationales.

2

Analytic Issues and Factors Affecting Deterrence and Assurance

INTRODUCTION

This chapter, which responds to Item 1 in the terms of reference (TOR), highlights key analytic issues, questions, and challenges that arise in attempting to deter adversaries and assure allies. It also provides definitions and sets the stage for discussions of analytic approaches in Chapter 3.

The word deterrence is often used as shorthand for a set of complex matters.[1] Figure 2-1 draws on classic strategic thinking to infer a set of de facto objectives for U.S. strategic planning including nuclear and other forces.[2] These objectives include (1) a generalized strategic stability that includes healthy change without aggression or arms races; (2) crisis stability; (3) the ability of the United States to act militarily as necessary in peacetime and in crisis, and, in the event of war, to fight effectively and limit damage to the United States, its allies, and other interests; (4) nonproliferation and other policy goals; and (5) other kinds of risk control such as those relating to the implementation of strategy, military-technical risks, and political

[1] See National Research Council (1997), chaired by GEN Andrew Goodpaster (U.S. Army [USA], retired) for related discussion.

[2] The objectives are drawn or inferred from such classic deterrence literature as Kahn (1960), Schelling (1960, 1966), and Morgan (1983, 2003) and from statements of senior officials (Schlesinger, 1974a,b; Brown, 1981; Slocombe, 1981; Brown, 1983; Department of Defense (2010c, 2014). The figure builds on Davis (2011). Other objectives are implicit, such as shaping the postcrisis and post-conflict environments.

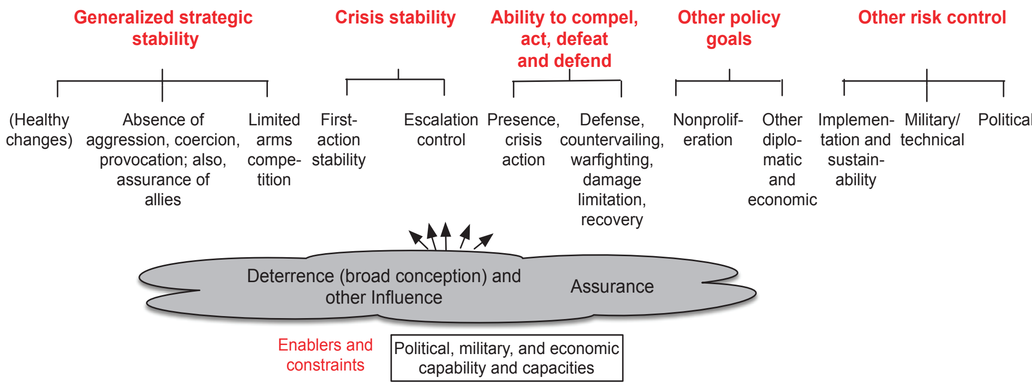

FIGURE 2-1 Objectives in strategic planning that includes nuclear forces. SOURCE: Adapted from Davis (2011), with permission by the RAND Corporation.

risks. Casual reference to the U.S. objective of deterrence, then, often involves much more than deterrence per se. A sharpened discussion requires tighter definitions.

DEFINITIONS AND DISTINCTIONS

Figure 2-2 illustrates a number of distinctions and subtleties that are reflected in the definitions listed in Table 2-1. The figure shows the adversary comparing two options (top), of which we prefer the one on the left (that might be "no action") and seek strongly to avoid the one on the right. It is common to refer to trying to "deter" the adversary from the decision on the right, but the adversary's behavior will actually depend on quite a number of considerations.

The adversary perceives pros and cons to each action, and we may affect those perceptions by various influences (red dotted items), including deterrence.[3] Our influences attempt to increase the attractiveness of the preferred option and to decrease (see the negative signs in the figure) the attractiveness of the option to be avoided. The adversary's decision, however, is subject also to factors that one cannot easily influence, such as his internal politics, nationalism, pride, and rationality.

Influences other than normal deterrence by threat of punishment include inducements or reassurances to an adversary who fears attack; coercive threats or actions to *compel* action; dissuasion by being able to deny an adversary's success

[3] Seeing deterrence as one element of influence is discussed in Davis and Jenkins (2002) and George (2003). See also George and Smoke (1974).

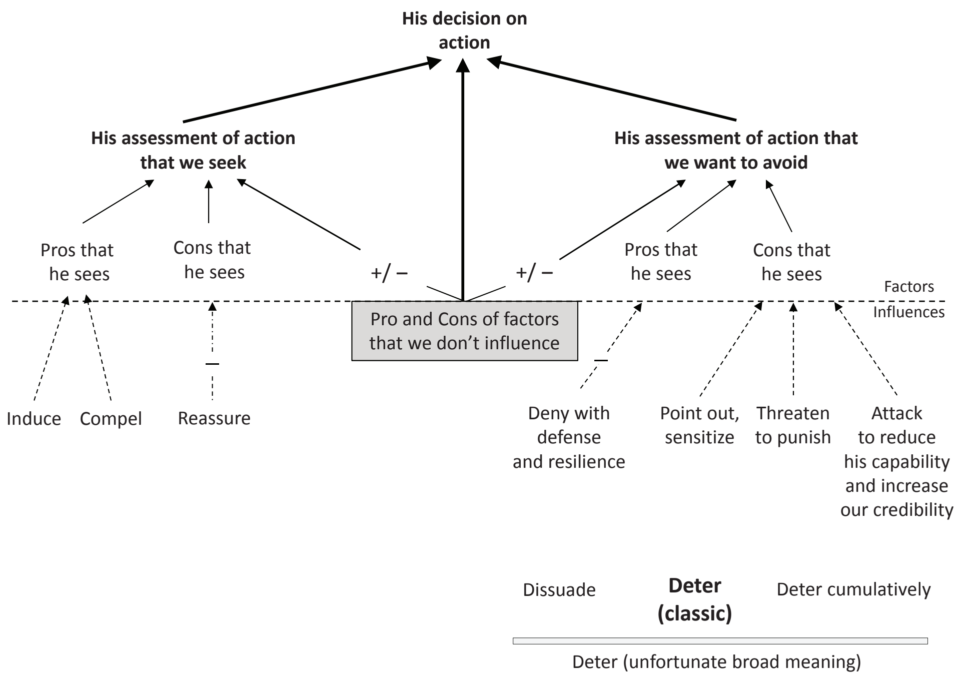

FIGURE 2-2 Relationships among concepts. SOURCE: Davis (2014a), reprinted with permission by the RAND Corporation.

with defense or resilience or by helping an adversary recognize courses of action more in the adversary's interest; and punishments for past actions to improve future deterrence—that is, to improve "cumulative deterrence."[4] Discussions sometimes use "deterrence" to refer, with regrettable looseness, to a combination of dissuasion, classic deterrence, and cumulative deterrence. The report recognizes this (bottom right of figure) with the umbrella term "broad deterrence" but attempts to be more specific in the related discussion.

With this background, Table 2-1 shows the key definitions used in this study. Two final observations are significant: (1) deterrent actions may or may not have much effect in "causing" the adversary's subsequent behavior because of the multiple influences at work simultaneously and (2) actions taken to deter may have unintended side effects, sometimes the opposite of those intended, as when a side's efforts to deter are seen as aggressive and reckless.

[4] Had the United States attacked Syria in 2013, it would have been to "punish now" so as to deter further use of chemical weapons.

TABLE 2-1 Definitions

Term	Meaning
Influence	Effects on the decisions of another party by, for example, positive inducements, persuasion, dissuasion, deterrence, compellence, and punishment.[a]
General deterrence	Deterrence over time in periods of peace. If successful, it will head off crises in which immediate deterrence would be at issue.
Deterrence (classic)	Convincing an adversary not to take an action by threatening punishment only if the action is taken but not otherwise [see also "broad deterrence," below].
Dissuasion by denial (often called deterrence by denial)	Convincing an adversary not to take an action by having the perceived capability to prevent success adequate justify the costs.[b]
Cumulative deterrence	The quality of deterrence at a given time due to the history of prior successful and failed deterrent actions, crises, and conflicts.[c]
Broad deterrence	A combination of the previous three.
Direct deterrence	Deterring an attack on the United States or its immediate interests. Direct deterrence is more likely to succeed than extended deterrence (see below), because the deterrent threat is inherently more credible.
Extended deterrence	Convincing an adversary not to take an action against the interests of an ally by the methods of broad deterrence.
Dissuasion	Persuading an actor (such as an adversary) from taking a particular action.
Compellence	Causing an actor (such as an adversary) to take an action despite its preferences to the contrary, by using or threatening to use military, economic, or political power.
Coercion	Causing an actor unwillingly to do something by use of force or threat. Deterrence and compellence are different kinds of coercion.
Assurance	Convincing an ally of U.S. commitment to and capability for extended deterrence for the purpose of dissuading the ally from developing its own nuclear arsenal.
Reassurance	Reducing fears of potential adversaries regarding U.S. intentions or the intentions of U.S. allies.

[a] See George and Smoke (1974), Davis and Jenkins (2002), and George (2003).

[b] We adjust the concept of deterrence by denial (Snyder, 1961) by expressing it as dissuasion based on adversary perceptions of potential gains and losses (Davis, 2014b). See also Waltz (1990) and Sawyer (forthcoming).

[c] Cumulative deterrence is important in Israeli strategy (Doron, 2004; Rid, 2012; Adamsky, forthcoming). It overlaps with the credibility component of deterrence but reflects the history of events that also affect psychological appreciation of and distaste for what the punishment would mean. That is, it affects perceived consequences and saliency.

STRUCTURING THE ISSUES

Are Nuclear Weapons Relevant?

Deterrence and assurance contribute to several higher-level objectives, as indicated by the gray cloud in Figure 2-1. The objectives referring to defense, countervailing, war fighting, and damage limitation may seem more appropriate to Cold War days than to now. However, they remain enduring objectives that are applicable in many military situations. They also apply when deterrence fails. Even if objectives are agreed, how best to build and employ nuclear forces has always been controversial. Presidents have long insisted on employment flexibility, complaining about the narrowness of options provided to them in operations plans. They have been concerned both about the immorality of indiscriminate use and about how overly blunt options undercut the credibility that the United States would use nuclear forces if it had to. Having no option other than Armageddon is, arguably, to have no option.[5]

As a result of such concerns, limited nuclear options were emphasized as part of flexible-response strategy, and by the end of the 1970s and after extensive analysis across three administrations, the United States settled on an even broader "countervailing strategy." The term countervailing was a nuance: Although assumptions about warfighting and war winning seem to lose meaning in scenarios involving massive nuclear exchanges, the United States wanted to assure that *any* Soviet leaders would conclude that no nuclear warfighting strategy could lead to meaningful victory and that the price would be too high.

Why is this relevant today when the Cold War is so long gone? The core reason is that the imperative to avoid nuclear war at all costs is not now, nor has it been, an inviolate and universally accepted principle of nature. During the Cold War, both the Soviet Union and the United States regarded nuclear weapons as valuable for coercive diplomacy.[6] They also developed first-nuclear-use options for scenarios that were deemed conceivable.[7] The North Atlantic Treaty Organization (NATO) developed and practiced operational doctrine for initiating nuclear use as needed to re-establish deterrence in the event of a Warsaw Pact invasion that could not be defeated with conventional forces. Despite an ostensible no-first-use policy, the Soviets had war plans for massive first use, which they characterized as preemptive.

[5] See Burr (2005) for archival data, including Henry Kissinger's comment that "To have the only option that of killing 80 million people is the height of immorality." The comment reflected President Nixon's strong discontent with the options provided him. He found the all-or-nothing options appalling and, according to an interpretation of a comment by Henry Kissinger, expressed unwillingness to order the war plan's execution (Mastny et al., 2013, p. 121).

[6] See Delpech (2012, pp. 61-80) for a comprehensive review.

[7] See a recent review (Long, 2008).

Finally, during the Cuban missile crisis, Fidel Castro had urged the Soviet Union to use nuclear weapons if Cuba was invaded, even though he presumably knew it would lead to the destruction of Cuba.[8] We now we know that the world was lucky to have escaped that crisis.[9,10]

Today, Russia regards nuclear weapons as a core element of its ability to deter China and NATO from nuclear or conventional attack[11] and has well-developed options for using them on the battlefield and geo-strategically with escalation control as a centerpiece. Pakistan regards nuclear weapons as a key to deterring a conventionally dominant India. Its programs appear to include tactical nuclear weapons, and its planning presumably includes preparing for at least limited nuclear warfighting.[12] Although Indian nuclear policy is ambiguous, Indian officials have spoken of being at liberty to use conventional force given their nuclear capability. Additional observations could be made regarding Israeli, North Korean, British, and French perspectives. The overall point is that nuclear weapons have played an important role in nations' foreign policies for a number of different reasons: Nuclear weapons have on occasion been considered usable, even when the condi-

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[8] Castro apparently saw the potential invasion of Cuba in apocalyptic terms, an attack of "Imperialism on Socialism." In a telegram to Khrushchev, he appeared to urge a nuclear strike on the United States in the event of such an invasion. See Garthoff (1992) and the original telegram at http://digitalarchive.wilsoncenter.org/document/114501.

[9] See Nathan (1992), Fursenko and Naftali (1997), Dobbs (2008), and Kokoshin (2012).

[10] Robert McNamara once said

> Had Khrushchev not announced publicly on the 28th of October—a Sunday—that he was removing the missiles, I believe that on Monday the majority of President Kennedy's military and civilian advisers would have strongly urged air attacks, with the likelihood of a sea and land invasion . . . . Some of us thought then the risks were very, very great. We underestimated them. We didn't learn until nearly 30 years later, that the Soviets had roughly 162 nuclear warheads on this isle of Cuba, at a time when our CIA said they believed there were none. . . . Had we . . . attacked Cuba and invaded Cuba at the time, we almost surely would have been involved in nuclear war.

(National Archives Project, undated).

[11] According to Russian scholars (Arbvatov and Dvorkin, 2013, p. 16), the official Russian statement is that

> the Russian Federation reserves the right to use nuclear weapons in response to the utilization of nuclear and other types of weapons of mass destruction against it and (or) its allies and also in the event of aggression against the Russian Federation involving the use of conventional weapons when the very existence of the state is under threat.

The final phrase reflects Russian concern about the current inadequacies of its conventional forces given the threat Russia sees from both China and NATO. All five members of the U.N. Security Council have no-first-use pledges to nonnuclear weapons states parties to the Nuclear Non-Proliferation Treaty (NPT), some with qualifications. China has a less qualified declaration in public, but some limits on its no first use pledge related to attacks on Chinese territory may exist.

[12] See Khan (2005). Feroz Khan, a Pakistani, was writing while serving as a visiting fellow at the Stimson Center and has since written on the history of the Pakistani bomb (Khan, 2012).

tions of mutual assured destruction exist, and nuclear weapons have been "brandished" as part of strategic communication.[13] There has never been a clean break between deterrence and warfighting, or between counterforce and countervalue attacks. Scenario details have matured and likely will continue to matter greatly. To reiterate, and despite successes in establishing international nonproliferation regimes and pressures in some areas of the world to eliminate nuclear weapons altogether, it is likely that some countries in some circumstances will in the future have powerful incentives for using or credibly threatening to use them.

What Do Nuclear Forces Help to Deter?

One of the most important contributions of nuclear strategic thinking in the 20th century was recognizing how the deterrent challenge varies with circumstances. Myriad scenarios should be considered, with certain distinctions being particularly important: (1) extended versus immediate deterrence; (2) direct versus extended deterrence; (3) deterring nuclear attacks versus deterring conventional attacks; (4) deterring small rather than large attacks; (5) deterrence before, during, or after war; and (6) deterring different countries or leaders (i.e., personalities, cultures, and mindsets matter).

What about today? Is the only significant role of U.S. nuclear forces to deter an adversary's use of weapons of mass destruction (WMD), as some believe? Or, do nuclear weapons have a continuing, albeit less direct role to play in deterring conventional aggression against U.S. allies by creating a "shadow"? The 2010 Nuclear Posture Review (NPR) takes a view somewhere in the middle, observing that the role of nuclear weapons in deterring conventional, chemical, or biological aggression continues but has declined.[14] Most recently, some have argued—quite controversially—that deterrence should also extend to preventing high-end versions of cyberwar—that is, cyberattacks so broad and destructive as to have massively destructive effects analogous in some respects to nuclear war. [15,16]

In fact, all extensions of scope beyond deterring use of nuclear weapons continue to be controversial. One view is that the other classes of attack are in a lesser league and can be deterred or countered without resort to nuclear weapons. Another view is that the most destructive but not-implausible versions of biological attack especially would be catastrophic. The Soviet Union had a massive biological

[13] See Bracken (2012) and Delpech (2012).

[14] See Department of Defense (2010b, p. 15).

[15] The report interprets "existential deterrence" as "deterrence due to fear of attack so catastrophic as to make details of both pre- and postconflict power balances irrelevant." To some, referring to existential deterrence is "getting real." To others, it seems like a cessation of critical thinking.

[16] See Defense Science Board (2013b) and rejoinders (Clarke and Steve, 2013; Colby, 2013).

warfare program,[17] Iraq pursued biological capabilities under Saddam Hussein (Zilinskas, 2000), and North Korea may have biological weapons (Bennett, 2013). Such weapons are extremely lethal.[18] It is well to note here that heuristics such as "nuclear weapons only deter nuclear use" are examples of how people have sought to categorize weapons neatly. If history is a guide, however, nations, regimes, and commanders will not respect categorical boundaries, especially if stakes are high enough.

What Should Be the Basis of Nuclear Employment Planning?

Modern discussion of nuclear matters, including possible reductions to very small numbers or even to zero, typically does not address what operational nuclear planning should focus on—even if merely deterrent options that, presumably, would never be triggered. The question is this:

> If deterrence requires credibility and if credibility requires operational capability, then employment planning is necessary. But what should the targets be and what capabilities are needed?

Perhaps some, such as proponents of depending solely on "existential deterrence," would argue that it is only "arsenals" that must be kept "safe, secure, and effective," without need for ready forces or ready-to-implement targeting plans. Even if this is so, it would be necessary that forces could be brought to high readiness quickly and that actual operational targeting could be decided at the time (with some preplanning). For that to be viable, however, the substantial background work, training, and development of alternative targeting plans would still have to deal with the same issues faced by U.S. Strategic Command (STRATCOM) today. Thus, the question cannot be avoided: What should be targeted by nuclear weapons and what does this imply for planning and operations?

The targeting question might be addressed from diverse perspectives. Some observations are as follows:

1. Despite the precedents in the Second World War that included carpet bombing, fire bombing, and atomic bombing of Hiroshima and Nagasaki, attacking population centers raises enormous moral and legal concerns, even if the attacks are nominally on collocated industry.

[17] See Leitenberg et al. (2012) and Albeck and Handelman (1999).

[18] See Lederberg (1999). Terrorist attacks are of special concern, although the application of nuclear deterrence is unclear in such scenarios and higher priority should probably be given to preparing defenses and adaptations (Danzig, 2009).

2. Further, such an attack would virtually guarantee a response in kind, if possible. Thus, would such an attack merely be part of mutual suicide? If so, how could the capability for such an attack provide credible deterrence?

3. Continuing from (2), would such capability be credible for deterrence? Strategists have been extremely doubtful since the 1950s.

4. By analogy with armies attacking armies rather than razing cities (something usually regarded as a momentous advance in civilization's norms), shouldn't nuclear targeting focus on threat, notably nuclear and comparably threatening systems rather than innocent civilians?

5. Alternatively, if the counter-nuclear-threat targeting is too difficult, shouldn't nuclear targeting focus on other military targets with the intent of crippling the ability of the target state to project force or maintain authoritarian control?

6. If presented with the need to actually employ nuclear weapons, wouldn't any U.S. President seek very limited options—for example, destroying a class of adversary forces or weapons, blunting an invasion, or demonstrating ruthless resolve?

It is not the purpose of this report to resolve these weighty issues but rather to lay them out candidly because they bear heavily on nuclear analysis and the methods that should be brought to bear in such analysis.

What Are the Key Principles for Thinking About Assurance?

Although mostly focused on deterrence, this study considers assurance issues at every stage. The committee heard directly from officials and officers who are intimately involved in related work.[19] Many of the methods used to evaluate military issues and the quality of deterrence can be applied to questions of assurance and even shared or conducted with partners (for example, studies, analyses, and political–military gaming) as part of assurance activities.

The committee did not identify a separate class of "assurance methods," and it is difficult even to characterize a framework or theory for this quintessentially diplomatic activity. Nonetheless, the following can be considered as contributing principles.[20]

1. *Even at its simplest, assurance is complex.* Even if deterrence is in fact strong, assurance can be demanding. Diplomats often claim that achieving assurance is

[19] This included a session with Bradley Roberts, until recently the Deputy Assistant Secretary of Defense for Nuclear and Missile Defense Policy, an earlier briefing by David Stein, Office of the Secretary of Defense (Policy), and an information-gathering session at U.S. STRATCOM in Omaha.

[20] This discussion draws in part on unpublished work by Ely Ratner for an earlier STRATCOM-sponsored study, on Wheeler (2010), and—for the last item—on Crawford (2003), which discusses "pivotal deterrence."

more difficult than deterrence itself because it involves building—and sustaining—trust and confidence among people, organizations, and countries.

2. *There is no single definition of "credibility."* Allies are not likely to assess credibility in the same way as the United States. U.S. reasoning often revolves around shared interests, U.S. capability, formal agreements, policy, and intent. Affected allies are rationally sensitive as well to how a nation's commitments may become slippery when fulfilling them becomes too risky or costly. The degree of assurance that can be achieved, then, is inextricably related to the credibility of extended deterrence.

3. *Assurance can have negative side effects.* It is possible for efforts taken in the name of assurance to encourage allies to take courses of action contrary to U.S. interests (and perhaps to the ultimate interests of the ally). This is why U.S. assurances have long been deliberately ambiguous on matters relating to China and Taiwan.

4. *Assurance involves all forms of national power.* U.S. success in assurance efforts often depend as much or more on its capability for coercive diplomacy as on its capability to deter. The strength of a security relationship depends, after all, not just on deterring particular actions but also on its effectiveness in influencing events more generally, sometimes coercively.

5. *What assures changes?* Assurance success in the current era depends on the United States being seen as successfully adapting to shifting power alignments in ways acceptable to the security partners. This issue is prominent not only in the Asia-Pacific region but also in the Middle East and along the borders of the former Soviet Union.[21]

The Department of Defense (DoD) is sensitive to these issues and has strived to engage officials and military officers from key countries—with site visits and in-depth discussions, not just exchanges of policy statements. One recurring issue is that influential allied representatives often see great value in forward-deployed systems, including nuclear-capable systems. Such deployments may not seem necessary or appealing to Americans given the demonstrated ability to fly long-distance missions and to redeploy forces if necessary, but they are seen as significantly improving the credibility of the U.S. commitment.

WHAT IS NEW IN THINKING ABOUT DETERRENCE AND ASSURANCE?

The preceding material was largely general. The following sections describe what is new about the current era and what has been learned from the past.

[21] See, for example, Research Group on the Japan–U.S. Alliance (2009).

Changes

Thomas Schelling (2012) wrote recently about the success of mutual deterrence between the Warsaw Pact and NATO but then observed

> What a simple thing that was, that bilateral mutual relationship! Just two parties, fully identified, sophisticated and "rational," fully reciprocal, with nothing at stake worth a war, no real territorial threats, at least after 1962, no great technological secrets, good diplomatic communication, especially after the "hotline" of 1963.

Schelling went on to discuss differences today. For the particular book, he was stressing issues raised by the terrorist threat, but many of the differences were more general, such as multiple adversaries, multiple motives, poor communications, no collaboration, no confidence in taboos, and no confidence in "rationality." To be sure, almost nothing is truly new for deterrence theory in that antecedents can usually be found. Nonetheless, as Table 2-2 suggests, some important differences of degree exist and some issues are indeed new.[22] One consequence of change is that it is now more necessary to study the possibilities of very limited nuclear exchanges and limited nuclear war. During the Cold War, the overwhelming emphasis was on general nuclear war (despite the attention to NATO's flexible response).

Have the Right Lessons Been Learned from the Past?

The lessons some draw from the Cold War are often dubious. It is sometimes argued, explicitly or implicitly, that (1) nuclear weapons are useful only for deterring use of nuclear weapons; (2) that deterrence in the Cold War ultimately came down to nothing more complicated than existential deterrence, which could be achieved with very few nuclear weapons; (3) that defenses are ineffective because the offense-defense competition favors the offense; and that (4) a Third World War was averted because of rational behavior under the reality (rather than the strategy) of mutual assured destruction. The first argument is false; the second is widely (but not unanimously) believed by experienced strategists to be false; the third reflects a judgment that was arguably valid at certain points in history but may not be true now or in the future; and the fourth argument gives only part of the story since the objective motivations for war between the Soviet Union and West were low in historical terms.

[22] Keith Payne makes similar points (Payne, 2008, p. 205 ff.), drawing contrasts with the Cold War, during which the United States and the Soviet Union had strong reasons for avoiding conflict. See also Davis and Jenkins (2002) and Lowther (2013), a recent book on deterrence from the Air War College. For discussion of technological issues, see Lehman (2013) in a recent book on strategic stability (Colby and Gerson, 2013).

TABLE 2-2 What Is New or Different?

Class of Issue	Changed Circumstance
Actors	More nuclear-weapon or nuclear-capable states, and bigger arsenals. Violent extremist organizations that may not be deterrable in the same manner as nation-states.
Strategic context	Potential for *n*-party arms races. Increased globalization that means damage from attacks would disrupt international commerce severely and anger nations worldwide.
Weapons and technology	Long-range precision conventional weapons for strategic attack. Dependence of modern nations on space systems and worldwide networking disruptable by physical attack or cyberwar. Implications of modern science for biological warfare. Accelerated advances and spread of strategic technologies. The expectation of future technologies that may alter basics such as how we think about command and control, air and missile defense, antisubmarine warfare, and survivability against nonnuclear forces.

What, then, are the better lessons? Some were stimulated by top-level war-gaming in the Reagan administration (Bracken, 2012). Although war games usually did not cross the nuclear threshold because of political sensitivities and the fact that such use would be a game-stopper interfering with other game objectives, the Proud Prophet exercise resulted in general nuclear war growing out of the "seemingly inexorable consequences of nations and organizations implementing their own strategies and doctrine" (Bracken, 2012, pp. 84-89). Bracken believes the exercise had a major, lasting, and sobering influence on the thinking of top officials.

Similar lessons have been drawn over the years stem from the RAND Corporation's "Day After Exercises" and from political–military war games at the Naval War College and elsewhere. Protagonists (often senior civilians and military officers) routinely "brandish" nuclear weapons ambiguously without intending to use. Misperceptions and miscalculations are common, with both acts of resolve and demonstrations of restraint having unintended results; the most important risks are sometimes ignored until too late, and participants take escalatory actions that might naively have been thought "unthinkable." Other sources of lessons include historical case studies (see Chapter 3) and often-candid reflections by past practitioners of nuclear strategy.[23] A "meta lesson" for today is that those working on deterrence and assurance should draw on diverse sources of knowledge.

[23] See Quinlan (2009), Delpech (2012), and observations made in various venues by former Secretaries of Defense James Schlesinger and Harold Brown. The committee received a briefing on such reflections by Larry Welch, a former Chief of Staff of the Air Force and president of the Institute for Defense Analyses. See also two recent studies (Utgoff and Wheeler, 2013; Coe and Utgoff, 2008).

TABLE 2-3 Selected Focus Issues

Category	Theme
Understanding deterrence and influence in modern contexts	Increased importance of general deterrence and cumulative deterrence. Need to improve and move beyond rational-actor assumptions. More complex regional/escalatory dynamics. The role of dissuasion by denial.
Planning and analysis	Dealing with expanded uncertainty. The relationship between defense and assurance. Anticipating the unexpected, geopolitically and technologically.
Attending to basics	Maintaining safe, secure, and effective forces.

WHAT ISSUES SHOULD ANALYSIS ADDRESS?

A core task for this study is identifying which issues involving nuclear forces should be of concern, which questions should be addressed analytically, and which methods of analysis might help. The following describes selected issues that appear to merit special attention and have significant implications for the discussion of analytic methods in Chapter 3. The themes fall into groups as indicated in Table 2-3: (1) understanding deterrence and influence in the modern context, (2) planning and analysis for future forces and operations, and (3) attending to basics. They are discussed in turn.

Increased Importance of General Deterrence

General deterrence—that is, peacetime efforts to deter conflict—is especially important because, if successful, it will head off what otherwise could become crises: events that are notoriously difficult to control. It is better for the states in question to avoid actions that take matters into potential danger zones than to plan on cleverly navigating the shoals of near-crisis situations.[24] The potential for "small" events to have large impact is worrisome.[25] Part of what is needed are called "rules of the road" that govern normal and crisis-time military operations and that can avoid or mitigate the escalatory consequences of more militarily conservative doctrine.

[24] See Morgan (1983, 2003).

[25] Davis and Wilson (2011) note the possibility of troublesome actions in East Asia such as preemptive island grabs or "incidents" on the high seas. See Colby and Ratner (2014) for arguments about the need for the United States to be more assertive.

Observation 2-1. Norms of Behavior. Because of the escalatory potential of even smallish conflicts, "rules of the road" are vague in important areas such as cyberspace, outer space, South Asia, the Middle East, and East Asia. Better ones are needed.

As an example, when U.S. naval ships were operating recently near the early operations of a new Chinese carrier and its escorts, China maneuvered a warship in such a way as to nearly cause collision with a U.S. missile ship. As for cyberspace, it seems evident that the technology for aggressive actions has proceeded faster than the understanding of likely and potential consequences. The most well-known example involves the Stuxnet worm (Sanger, 2012), which had temporary effects of the sort intended, but which also had subsequent unintended effects broadly. Most recently (Spring 2014), related problems arose as Russia absorbed Crimea and threatened the rest of Ukraine.

While confidence-building measures and rules of the road can have undesirable or unintended consequences, recognized norms of behavior that encourage restraint can be useful. Improving general deterrence and related rules of the road will necessarily involve government-wide discussions, government-to-government negotiations, and military-to-military interactions. However, it should be noted that developing well-understood international norms (rules of the road) favorable to the United States depends on the national leaders of the countries in question seeing some value in more restrained, cautious interactions. That condition may or may not apply to China and Russia in what they think of as their natural spheres of influence.

Improving and Moving Beyond Rational-Actor Assumptions

The dominant paradigm for theoretical discussion of deterrence and even for codification of concepts in doctrine is that of rational-actor decision making. In this paradigm, one deters by convincing the adversary that the risks of the action to be deterred outweigh the benefits, compared to inaction. The degree to which the paradigm relies on the rational-actor model can be seen in the terminology, which refers to affecting the adversary's "calculus."[26] This paradigm can be powerful when the emphasis is placed on the *adversary's* reasoning and conclusions, which in turn are affected by the adversary's objectives, values, and perceptions. It can even anticipate and explain seemingly irrational behaviors such as suicide bombing by terrorists by understanding martyrdom in behalf of a people, cause, or god. That requires extending the rational-actor calculus to go beyond materialistic values

[26] This concept can be found in multiple scholarly and official sources (USSTRATCOM, 2006). The committee was briefed on interpretations by Jonathan Drexel and Lt Gen Robert Elder (USAF, Ret.).

and allow for, for example, nationalism, identity, religious convictions, honor, and self respect.[27,28] Substantial success has also been reported in the ability to use rational-actor theory to predict political maneuverings and eventual compromise in organizations and foreign affairs involving multiple actors.[29]

Although rational-actor approaches can, then, be improved, there are also limitations because people do not always behave rationally and because, even if they do, their reasoning may not be understood. There is a long history of trying to get into the adversary's head when contemplating deterrence, although the history of efforts to do so has been decidedly mixed. Fortunately, deterrence can sometimes work against adversaries whose reasoning is not understood.

Even with good attempts to understand the adversary, the rational-actor paradigm—especially the version that assumes a desire to maximize expected subjective utility—has serious shortcomings.[30] The problems include these: (1) The adversary may not have objectives, values, and a way to evaluate options; (2) Even if he does, they may not be inferable with available information; (3) In many circumstances, *stable* "utility functions" do not exist: leaders may not know their "true" objectives and values and, in any case, those may change as matters evolve.

The first point has been made by Patrick Morgan, who notes that policy makers often defer deciding on their objectives and value trade-offs, expecting to learn from events and interactions and not wanting to tip their hands early (Morgan, 2003). It is of interest to note how little eventual U.S. war objectives in Iraq and Afghanistan relate to those stated at the outset. More generally, policy research has long demonstrated that many of the most important policy challenges involve "wicked problems" that have no clear solutions. Instead, people work the problems until, as the result of interactions, events, and sometimes weariness, they discover acceptable solutions that reflect history, personalities, and process.[31] That is, solutions emerge.

The second item is well illustrated by the case of Saddam Hussein. Only in retrospect is it clear that he had put on hold his nuclear program but kept that

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[27] See Berrebi (2009) for empirical analysis of terrorist behavior.

[28] Henry Kissinger observed, looking back on Egypt's invasion of Israel in 1973, that "our definition of rationality did not take seriously the notion of Egypt and Syria starting an unwinnable war to restore self-respect" (Kissinger, 2011).

[29] The most important work of this type was initiated by Bruce Bueno de Mesquita in the 1980s (Bueno de Mesquita, 1981). Related work continues (see, e.g., National Research Council, 2011, and Abdollahian et al., 2006, with the Senturion model). Similar work at RAND has been led by Eric Larson. Such work, however, is typically not about deterrence per se.

[30] The literature on the subject is lengthy: for example, Jervis (1976), Jervis et al. (1985), Green and Shapiro (1994), Lebow and Stein (1989 and other articles in the same issue of *World Politics*), Morgan (2003), Kahneman (2011), and Davis (2014b).

[31] See Rosenhead and Mingers (2002). Wicked problems are more heavily studied in Europe than in the United States, but the approaches resonate with many scholars of policy analysis.

fact secret from nearly everyone in order to influence the United States, Iran, and potential domestic rivals.[32] The instability of utility functions is a a fundamental but often-undiscussed problem (Davis, 2014b). Everyone does things that, in retrospect, were not in their best interests even though they seemed right at the time. Leaders are no different, and there is ample laboratory evidence of related matters, including the celebrated paradoxes of behavior described below.[33]

The failure of U.S. planning that led to the Bay of Pigs fiasco has long been described as a peacetime example of group-think.[34] The widely accepted notion that heavy-handed threats of military attack will deter states such as Iran from developing nuclear weapons, or even having virtual weapon-system capability, may be a modern example (however sensible the goal of persuading Iran to do otherwise). The conditions under which threats do or do not work are not always well understood and can change.

It is perhaps surprising that the literature on deterrence theory continues to be dominated by rational-actor theory, but this is changing with the more widespread appreciation of lessons from psychology accumulated over the last half century or so. Which types of approaches can help in going beyond rational-actor assumptions? The answers include leadership profiling, qualitative cognitive modeling, human gaming with role-playing, the use of alternative adversary models to hedge against uncertainty, and—in principle—even agent-based simulation. Most important, however, is doing the "hard thinking." After all, people like Herman Kahn and Thomas Schelling discussed many ways in which behaviors would depart from what is ordinarily thought of as rationality.

[32] A mass of information is now available on Saddam Hussein's thinking in both 1990-1991 and 2003 from extensive interviewing, his own lengthy discussions with an FBI questioner while in custody (Woods and Stout, 2010; Woods et al., 2011; Woods, 2008), and even audio and video tapes that Saddam recorded of private conversations (Woods, 2012, p. 4).

[33] These have been summarized by Nobelist Daniel Kahneman (Kahneman, 2011) and in a popular book on behavioral economics (Thaler and Sunstein, 2009). Decades of research now exists on actual decision making and behavior, on the role of heuristics and biases, and the sometimes-helpful/sometimes-hurtful role of intuitive decision making (Gigerenzer and Selten, 2002; Klein, 2001, 1998). Those who support decision making should seek to achieve the advantages of both the heuristics-and-biases and naturalistic approaches, while mitigating their shortcomings (Davis et al., 2005; Kahneman, 2011). It is also important to reject the false dichotomy of rationality and psychology (Mercer, 2005). Interestingly, some practitioners of rational-actor modeling have found ways to incorporate some of the nonrational considerations while preserving analytic virtues of the earlier methods. See, for example, Bueno de Mesquita and McDermott (2004).

[34] See Janis (1972).

Planning Under Uncertainty

Analytic conclusions about deterrence are often dominated by the assumptions of a planning scenario even though such scenarios are notoriously unreliable and the odds of error are great. The challenge of planning under uncertainty has bedeviled decision making for millennia. This is especially the case for situations of deep uncertainty in which we do not know the relevant probability distributions (if they exist), understand the underlying phenomena, or know how to formulate the decision rigorously. Considerable technical progress has been possible due to the confluence of theoretical work, computational advances, empirical psychology, and other efforts. Addressing deep uncertainties need not mean paralysis; instead, it means pragmatically recognizing and bounding them, assessing the relative significance of the many such uncertainties, and identifying hedges and adaptations.[35]

Less work has been published on deep uncertainty in connection with deterrence and assurance, but a review of modern decision science for the Air Force Office of Scientific Research drew on historical lessons about flaws in top-level U.S. national security planning in crisis and implications from decision science.[36] A major conclusion was that it has been common for flawed decision making to be driven by best estimates about the adversary and that it should be a matter of doctrine for high-level decision-aiding to seek strategies that hedge against potential misunderstanding about the adversary. The report suggested using alternative cognitive models,[37] as one mechanism for doing so, pointing out that the empirical evidence is that causing people to entertain even two alternative constructs of how the adversary may be reasoning opens minds, which in turn makes hedging and preparing for adaptation easier. In contrast, devil's advocate methods often fail because the other position is too heavily discounted and discussions become personalized. The recommended approach is to make consideration of alternative assumption sets more routine and analytic, even doctrinal, depersonalizing the discussion.

Finding 2-1. Deep Uncertainty. Planning to support deterrence and assurance with both current operations and longer-term programs to organize, equip, and train is characterized by deep uncertainty, described more fully in Chapter 3. Nonetheless, methods exist for dealing with such uncertainties effectively, primarily by hedging and capabilities for adaptation.[38]

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[35] See section on exploratory analysis in Chapter 3.

[36] These aspects of the study were not published at the time because of sensitivities, but a published product (Davis et al., 2005) includes suggestions for decision support motivated in part by history as well as psychological research (pp. 83-93).

[37] See National Research Council (1997) and Davis (2010) and references therein.

[38] See Hallegatte et al. (2012).

Test Cases for Planning

The need for tailoring deterrence is hardly new.[39] What is more important is deciding on the "difficult cases" on which deterrence studies should focus—especially when it is not known what crises will occur in the future, or even the circumstances of tomorrow's crises. Ideally, test cases for planning emerge from in-depth examination of possibilities followed by identification of those cases that, if planned for, will likely provide the capabilities needed to deal with actual crises when they arise. Table 2-4 provides key questions suggesting test cases for analysis. The questions are grouped by the committee in the categories of Peer, Near-Peer, Regional (both Responsible and Rogue), and Nonstate Actors (see Table 2-4).[40]

Reexamining Ballistic Missile Defense with Extended Deterrence in Mind

One theme that emerges from discussion of modern-day deterrence and assurance is the increasing significance of ballistic missile defenses (BMD). This is indicated by the intense and dedicated efforts of Japan and the increasing interest of other states in these systems.[41]

Those recalling the Cold War often are skeptical about BMD, seeing offense as more cost-effective than defense and ineffective only against moderately sophisticated countermeasures. However, effective defenses against lower-level threats currently exist, and many of these could be substantially upgraded. Further, the technological balance between offense and defense changes over time. Open minds are important. Still, serious doubts exist regarding the technical viability of effective BMD against large, advanced attacks or even against small attacks by "advanced rogues." These issues are at the center of the credibility of U.S. extended conventional deterrence to critical allies such as Japan and South Korea.[42] DoD includes BMD prominently in its comprehensive approach to regional security discussions with Middle Eastern and Asian-Pacific nations (the initiatives also deal with cy-

[39] The strategist Fred C. Iklé sometimes observed wryly that one of the big lessons was that it was necessary to remember that there is no Red and Blue, but instead specific actors such as the United States and Soviet Union (Iklé, 2005).

[40] Similar questions are expressed by Keith Payne (2008), who draws on disquieting historical events when expressing skepticism about dependence on deterrence. See, for example, 334 ff.

[41] See a Japanese-U.S. study (Research Group on the Japan–U.S. Alliance, 2009).

[42] One recent study (National Research Council, 2012) strongly criticizes current DoD programs. Other studies have been more optimistic about the theoretical viability of boost-phase defenses against North Korea and more pessimistic about prospects for effective mid-course discrimination (American Physical Society, 2003; Sessler et al., 2000). Still others are quite critical of current programs for many reasons, including inadequate testing (Coyle, 2013).

TABLE 2-4 Key Questions Suggesting Test Cases for Analysis of Deterrence

Type of Adversary	Stressful Question
Peer	Could Russia find itself providing nuclear deterrence enhancement to regional players such as China or the DPRK, which could transform regional escalatory calculations into global deterrence dynamics?
Near-Peer	Might China, in a crisis involving Taiwan, see the issues as raising core values (what might even be seen as "sacred values") about the very nature of China and her place in the world, rather than as disputes about a small island nation with different attitudes but good economic relations with the Mainland?[a]
	Would Chinese military figures interpret events in terms of the United States attempting to squelch China's natural and proper aspirations as a great power, in which case the stakes would loom larger than might seem "reasonable?"
Regional	Might a future authoritarian leader of a rogue state, analogous to a Saddam Hussein, prefer going down with destruction of his enemies to accepting an island retirement or public hanging?[b] Would he see events apocalyptically rather than pragmatically?
	Might a future leadership of a state such as North Korea see its only possible route to success being to deter the United States, and the only route to success in that being willing to use nuclear weapons on a limited basis against our regional allies, our forces deployed forward such as aircraft carriers, or even the U.S. homeland such as submarine or bomber bases?
	Might the United States be self-deterred from decisive intervention in protection of an ally because of the credible threat of nuclear attack? What would the nuclear deterrence implications be for the United States of the breakout of nuclear use between India and Pakistan, especially if China were to support Pakistan, etc.?
Nonstate	How might extremist nonstate actors such as an al-Qaeda use or brandish weapons of mass destruction? What role can deterrence and assurance play in such cases?

[a] Sacred values have been addressed with deep social science research (Atran and Axelrod, 2008; Atran, 2010). Such values often lead to behaviors that appear to others as irrational; they are "ignored only with peril when discussing deterrence. Significantly, such matters interact with politics, as when Slobodan Milošević recreated ancient ethnic tensions in firing nationalistic emotions. Another example is how China's Communist Party has "created" sacred values with respect to Taiwan's relationship to China.

[b] Such possibilities were discussed at the end of the Cold War (Watman et al., 1995; Wilkening and Watman, 1995).

bersecurity, space resilience, and other matters).[43] It is important to resolve the technical questions to inform both investment and policy.

Observation 2-2. Missile Defense. Because regional and intercontinental missile defenses have become so important to extended deterrence and assurance, a new

[43] The comprehensiveness of the approach can be seen in some recent Department of Defense reports (2014; 2010a, pp. 31-35; 2010b).

round of intensive research and debate is needed—with the best science and *independent* assessment available—to assess what is truly feasible.

Observation 2-3. Extended Deterrence. As during the Cold War, there are inherent credibility problems when the United States seeks to extend deterrence to allies by using nuclear threats against nations that also possess nuclear weapons and could strike the United States. *Reassurance efforts, however zealously attempted, may not be persuasive to allies for understandable reasons.*

This observation may surprise some readers, but longstanding U.S. allies are having public discussions that include advocates of exploring nuclear weapons options.

Observation 2-4. Dissuasion by Denial. Dissuasion by denial is especially important for the era lying ahead. Relying entirely on the threat of punishment, especially nuclear threat, is fraught with risks—more so than in the past.

What methods might be useful in addressing such matters? In-depth scientific and engineering-level analysis is needed, along with gaming and game-structured modeling, among others. Chapter 3 discusses a number of these.

Anticipating the Unexpected: Technological and Other Drivers of Change

The pace of technological change increases the likelihood of technological surprise with strategic consequences.[44] The synergistic advances in information technology (IT), computation, materials, advanced manufacturing, exotic sensors, enhanced energetic materials and fuels, and the like may have direct effects in the areas of air and missile defenses, advanced conventional munitions, ballistic and cruise missiles, antisubmarine warfare, cyberwarfare, counter-space capabilities, and others which could undermine traditional nuclear deterrent forces. These are familiar and enduring challenges for U.S. planners and need no elaboration.

A rather different great challenge is that technologies such as ubiquitous sensors, the Internet, and smartphones are opening the world with the prospect of great situational awareness and communication. At the same time, cyberattack, electromagnetic pulse, and critical infrastructure vulnerabilities raise the prospect of suddenly losing awareness and connectivity. Rapid changes from one state to another are possible, creating a new kind of potential instability.

[44] For more background, see Lehman (2013), from which some of the committee's discussion draws, Bracken (2012), and Defense Science Board (2009, 2010).

In contemplating strategy to avoid or mitigate strategic surprise, past lessons should be recalled. These include (1) nations and nonstate actors do not always follow the paths taken by the United States; (2) silver bullet technologies are rare, but accretion of lesser capabilities can have similar effects; (3) the variety of technologies available, many close to military application, increases the chance of surprise; (4) many military technologies have different values for different players or scenarios; and (5) in a complex world, precise predictions of events and timing is difficult, and, even when predictions are correct, responses are seldom timely and often ineffective (Lehman, 2013).

What can be done? A principle is that strategy should at once seek vigorously to effectively anticipate possible major developments *and* lay the groundwork for mitigating consequences and exploiting opportunities. History shows that surprise often has badly adverse effects not because events were unforeseeable, but because nothing was done even when warnings were observed or because the ability to adapt to surprises proved poor, or both. Which methods might help? Modern simulations, exploratory analysis, and studies can help by generating a richer understanding of possibilities and consequences, and perhaps by helping to find ways to prepare or hedge. So also, certain types of human gaming can be very helpful, as illustrated by the years of experience with such games by DoD's Office of Net Assessment, "Foresight exercises" used in planning social policy and various scenario-based methods used in both national security work and private enterprise. These and others are discussed in Chapter 3.

Maintaining the Reality and Perception of Safe, Secure, and Effective Nuclear Forces

Perceptions and Assurance

Deterrence and assurance depend on both the reality and perception, by ourselves and others, of the safety, security, and effectiveness of nuclear forces. Perceptions vary on what nuclear weapons and their delivery systems and infrastructures can do, what they are for, and how others perceive them (a core element of assurance). For example, some allies feel more assured by local deployments while others feel less secure. Some allies have wanted systems that they see tangibly as "their nuclear umbrella," such as the TLAM-N sea-launched cruise missile, while others have been satisfied seeing central system components such as sea-launched ballistic missiles. Even the nature of individual nuclear warheads can be controversial. The value of reducing the yields of warheads is emphasized by some as a sign of restraint or an act to increase their credibility as a deterrent.

Potential adversaries may also have different perceptions of the significance of force characteristics. The Soviet Union placed a greater emphasis on geographical location of forces than did the United States, with NATO's forward-deployed forces seen as strategic because they could hit the Soviet homeland. While the United States emphasized the robustness, flexibility, survivability, and agility of a strategic triad, the Soviet Union relied heavily on the coercive power of its highly multiple independently targetable reentry vehicles (MIRV)ed, liquid-fueled heavy missiles. The United States has eliminated battlefield nuclear weapons and keeps only a small force of air-delivered tactical weapons. In contrast, Russia has shown renewed interest in modern, low-yield tactical and battlefield weapons. Other measures on which perceptions vary include fast versus slow flyers, alert rates, unit versus force survivability, day-to-day versus generated force postures, individual versus force performance, dependence on warning, and safety and security measures. This study did not examine such issues in detail but thought that they should be highlighted in future Air Force and DoD efforts to address safety, security, and effectiveness.

Efforts to assure that forces are safe, secure, and effectiveness should recognize and deal explicitly with alternative perspectives on how to measure them, thereby anticipating and dealing with perceptions crucial to both deterrence and assurance.

Weapons and the Stockpile

The National Nuclear Security Administration (NNSA) within the Department of Energy has the responsibility for maintaining a safe, secure, and effective nuclear weapons stockpile without underground nuclear testing. It provides an annual report to the Congress (Department of Energy, 2013). The current weapons stockpile and the design technology within it are old. According to the NNSA website,

> Most nuclear weapons in the U.S. stockpile were produced anywhere from 30 to 40 years ago, and no new nuclear weapons have been produced since the end of the Cold War. At the time of their original production, the nuclear weapons were not designed or intended to last indefinitely.[45]

The absolute and relative ability of different nations to sustain existing nuclear weapons, or perhaps to design and deploy reliable "new" nuclear weapons without testing, is subject to debate. Although what is meant by "new" or "modernized" nuclear weapons involves a range of definitions and considerable debate, many scientists believe that it is possible to develop and deploy some "new" or "modernized" nuclear weapons without full-scale testing. Indeed, China, Pakistan, and Russia have taken that course.

[45] For additional information, see NNSA, "Maintain the Stockpile," http://nnsa.energy.gov/ourmission/managingthestockpile, accessed January 29, 2014.

Prohibiting actual weapon-detonation tests has, under the Strategic Stockpile Management Plan, forced U.S. reliance on subcomponent and noncritical nuclear tests, analysis, and scientific modeling and simulation. The program includes life extension efforts, updating subsystem technology and components to improve reliability and safety, and replacing end-of-life components. An alternative approach, the Reliable Replacement Warhead program, a program to develop a family of "new" warheads embodying advanced technologies and designs intended to be highly reliable and more sustainable (Congressional Research Service, 2005) was terminated in 2009. Consequently, the Life-Extension Program (LEP) remains the main mechanism for achieving sustainability. This program is expensive, which is why the Stockpile Stewardship and Management Program 2014 (Department of Energy, 2013) calls for a reduction in the types of nuclear warhead designs in the inventory that need to be sustained. This plan calls for reducing the B61 series to just the new B61-12, which will consolidate the B61-3, -4,-7, and -10, completing the W76-1 LEP earlier, and a W88 Alteration program. The long-term plan is the so-called "3+2 vision," which calls for shrinking the stockpile to just three ballistic missile warheads and two air-delivered warheads. Although this would limit flexibility for future systems and increase some risks associated with common-mode failures (while perhaps reducing others), it would greatly reduce the cost of maintenance, safety, and support of the inventory, while retaining a strategic-upload hedge in the ballistic missile force at lower numbers and cost. Whether this strategy can be sustained with adequate funding over the long term remains to be seen.

Are these judgments valid today? Are things better or worse? The committee did no independent research on these matters, but committee members were concerned about patterns of decision and behavior on weapons (described in briefings to the committee) that are at odds with what would ordinarily be expected for critical systems that are supposed to be safe, secure, and effective. Proponents of the current approach point to past testimony and reports from officials, general officers, and scientists, which would seem to provide confidence in such matters. However, in the committee's reading they underplay troubling judgments. Five years ago, a congressional commission chaired by William Perry and James Schlesinger (United States Institute of Peace, 2009, pp. 40-41) reported as follows:

> The possibility of using this approach [current policy] to extend the life of the current arsenal of weapons indefinitely is limited. It might have been possible to do so had the United States designed differently the weapons it produced in the 1960s, 1970s, and 1980s. But it chose to optimize the design of the weapons for various purposes, for example, to maximize the yield of the weapon relative to its size and weight. It did not design them for remanufacture. This approach also requires that the United States utilize or replicate some materials or technologies that are no longer available. Designs constraints also prevent the utilization of advanced safety and security technologies. . . . The process of remanufacturing now underway introduces some uncertainty about the expected operational reliability

> of the weapons. So far at least, the directors of the weapons laboratories have been able to certify that they retain confidence in the remanufactured (and other stockpiled) weapons. But there are increasing concerns about how long such confidence will remain as the process of reinspecting and remanufacturing these weapons continues. Indeed, laboratory directors have testified that uncertainties are increasing.

Again, the committee did not have the time or budget for independent research on these matters, which relate strongly to the subject of its report and are important to the Air Force. It seems likely that at some point—despite the sensitivity related to these topics and the likely disruptive effects—the nation will review all of these matters and either reaffirm or alter stockpile-related policies and programs. If a clean-sheet-of-paper approach is taken, the committee believes that, while new analytic methods will be useful and internal peer review should be strengthened, it would also be valuable to give a major role to scientific and technical experts from outside of the current nuclear enterprise. Such experts would have fresh eyes and would have more independent perspectives with respect to the feasibility, wisdom, and affordability of continuing to repair and replace components developed decades ago.

Nuclear Command and Control

Another crucial subject that the committee was unable to look into during its short study was nuclear command and control. Logically, this deserves to be covered in a study of nuclear deterrence and assurance. Further, it is an important and troubled subject area. DoD initiatives in the last several years, championed by Ashton Carter while he was Deputy Secretary of Defense, sought vigorously to remedy problems of technological obsolescence and various other problems at the nuclear-enterprise level. Little public information is available as yet about what progress has been made and what remains to be done. This report can only highlight the problem area as one worthy of top-level attention, especially by the Air Force, the Navy, and DoD. The relevant analytic methods already exist, so the subject is not addressed in Chapter 3 or the remainder of the report. Nor are issues related to management of the nuclear enterprise, as discussed in a report chaired by James Schlesinger in the wake of weapon-mishandling incidents that led to the dismissal by Secretary Gates of the Secretary and Chief of Staff of the Air Force.[46]

Given the breadth of challenges involving the nuclear enterprise and particularly the Air Force role within it, there is need not only for improved policies and management, which has been discussed elsewhere (as in the references cited above and DoD directives), but also on the analytic front.

[46] See Schlesinger et al. (2008a,b) and a follow-up by the Defense Science Board on response by the Air Force (Defense Science Board, 2013a).

Finding 2-2. Analytic Framework. Because the U.S. approach to strategic deterrence and assurance needs to be continually adapted, a management plan is required that defines comprehensively the set of *continuing* analytic foci, which includes nuclear command and control; air and missile defense; cyber, space, geostrategic, and technological changes; and the challenges of tailoring deterrence and assurance to adversaries and allies. This analytic management plan is in addition to tasks related to weapons, forces, personnel, and the nuclear enterprise in general.

CONCLUDING REMARKS

This chapter has sought to lay out the issues and challenges. Chapter 3 discusses methods and tools that seem valuable for future study of, planning for, and operations of nuclear forces. It prefaces that discussion with strong words emphasizing that the expertise and sophistication of analysts is more important than improvement in methods.

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3

Selected Discussion of Tools, Methods, and Approaches for Deterrence and Assurance

INTRODUCTION

The committee reviewed analytic tools, methods, and approaches (collectively referred to henceforth as "methods") to address deterrence and assurance problems. It drew on members' prior expertise and previous reviews and held as information-gathering meetings. This chapter summarizes by identifying—with caveats—methods that have significant potential. Some general observations include the following:

1. *None* of the methods are "commodities" to be purchased to find "answers." Rather, they are merely aids to research, analysis, and decision making.
2. The value of analysis depends primarily on the talent, education, and experience of the analysts and their work environments.
3. Analysis quality is greatly improved if the people involved have been exposed to an interdisciplinary range of methods in the course of their careers through classroom learning, experiential learning (e.g., gaming), analysis, and practical experience.
4. Analytic organizations need *method suites*—a plentiful *kit bag*. For a particular purpose, the analyst may use intellectual capital, draw from the kit bag, or reach out to experts in applying the methods well.
5. *Significant* improvements in deterrence and assurance analysis are possible with synthesis using hybrid methods. The analysis community has tribes that do

not routinely interact, but much can be gained by forcing interactions (e.g., among gamers, modelers, empiricists, and analysts).

6. In looking back to 20th-century developments in deterrence and assurance theory, the biggest payoffs were insights, frameworks, and strategies rather than the nuts and bolts of methods. The primary benefit of game theory, for example, was facility not in solving academic game-theory math problems but in conveying concepts such as how to recognize prisoner-dilemma-type tensions, opportunities for a non-zero-sum game approach, and the pressures creating Chicken-game behavior.

Observation 3-1. Building Air Force Subject Matter Expertise. Improving analysis of deterrence and assurance problems will depend on the systematic education and nurturing of experts that exposes them over time to a rich suite of methods.

Finding 3-1. Long-Term Career Development. Education and nurturing of experts in deterrence and assurance will not happen without a management plan to do so in the Air Force (and other services, particularly the Navy), partly in coordination with joint assignments but also bearing in mind longer-term career development and assuring adequate expertise (a Service responsibility).

After considering a much broader range of methods, the committee pruned to the still-sizable list in Table 3-1. The leftmost column groups the methods in three major classes: those that help to collect, organize, or analyze data; those that involve knowledge structuring, model building, and theory building; and those for analysis to aid decision making. The committee did not include methods regarded as simply part of the baseline (e.g., operations research, statistics, quantitative political science, simulation, standard game theory, and standard decision analysis) or as having less potential for deterrence and assurance. Subsequent columns in Table 3-1 connect to the issues identified in Chapter 2 as particularly important for the study. The committee identified some methods relevant to all of those issues. The number of bullets shown in the table cells convey a rough sense of relative strength with no pretense of rigor.

The following sections cover the individual methods in the left column in the order shown (readers may wish to proceed in a different order). Level of discussion varies based on the methods' relative familiarity, their significance to the study, and the committee's use of appendixes for detail. The issue of validation is discussed along the way.

TABLE 3-1 Selected Methods to Address Issues in Analysis of Deterrence and Assurance

Methods	General Deterrence	Test Cases for Planning	Beyond Rational Actor	Planning Under Uncertainty	Anticipating the Unexpected	Safe, Secure, and Effective
Empirical and quasiempirical						
Data collection	••	••	••	••	••	
Crowdsourcing						
Data mining						
Social science analytics	••••	••	••••	••	••	
Case studies and narratives						
Content analysis and profiling						
Social network analysis						
Gaming and computational experimentation	••••	••	••••	••	••	
Human gaming						
Computational experimentation						
Knowledge organization, modeling, and theory						
Frameworks and qualitative modeling	••••	••••	••••	••••	••	••
Broadened framework of decision making						
Complex adaptive systems						
Causal system depictions						
Qualitative system modeling						
System diagrams						
Factor trees, cognitive maps and models						
Qualitative game theory						
Computational modeling		••		••	••	
System dynamics, Bayesian nets, influence nets						
Game-structured agent-based modeling						
Modeling of limited rationality						
Analysis						
Analysis methods	••••	••••	••••	••••	••••	••••
Leadership profiling						
Analyzing receptivity issues						
Exploratory analysis and robust decision making						
Strategic portfolio analysis						
Synergy across methods	••••	••••	••••	••••	••••	

NOTE: Number of bullets indicates subjectively assessed relative applicability.

EMPIRICAL: DATA COLLECTION AND SOCIAL SCIENCE ANALYSIS

The committee begins with empirical methods for crowdsourcing and mining of big data.

Crowdsourcing

Crowdsourcing taps into the knowledge of a group of people with diverse perspectives, sources of information, or ideas about an issue of interest. It reflects the Aristotelian view that wisdom is to be found in the mean: that querying numerous individuals with knowledge of different aspects of a problem will produce the most comprehensive and truthful picture. Crowdsourcing is most commonly associated with extraction of knowledge from geographically distributed groups, especially via the Internet. It has a different purpose and character than usual public polling.

One approach to crowdsourcing uses a wiki-type collaboration information system that allows knowledgeable people to modify information until the crowd reaches relative consensus. Another approach has "information markets" in which invited or self-selected participants bet on the likelihoods of future events or responses to those events. This approach can yield on-the-ground information from, for example, locals, aid workers, journalists, and others. Web-based methods, especially where immediacy and absolute precision are unnecessary, can be significantly less costly than other collection methods

Caveats. The cautions in interpreting crowd-sourced results are similar to those for interpreting public opinion polling. What types of individuals contributed? Did they have good information? What were their likely biases and how representative were they for the information asked? Second, variation is important. Were there significant outliers or a bimodal distribution, in which case the aggregation could be misleading? A problem related to the first caution is that it can be difficult to identify, check, and incentivize the most appropriate individuals to contribute. In particular, government-run crowdsourcing may be viewed with suspicion. For this or other reasons, private companies can sometimes do better in this regard.[1]

Big Data Mining

Experiments, observations, and numerical simulations in science and business are currently generating terabytes of data, verging on petabytes and beyond.[2] In contrast to traditional isolated analysis, the paradigm for "big data" is often for

[1] Companies offering crowd sourcing analyses include Monitor 360 and Wikistrat. RAND researchers have also developed a system Called ExpertLens (Dalal et al., 2011).

[2] Terabyte, petabyte, and exabyte correspond to 10^{12}, 10^{15}, and 10^{18} bytes, respectively.

highly distributed groups to share data routinely.[3] Analyzing such information has led to breakthroughs in such fields as genomics, astronomy and high energy physics. The scientific community and the defense enterprise have long generated and used large data sets, but the commercial sector is now a major player. Google, Yahoo!, and Microsoft have data in exabytes. Some social media (e.g., Facebook, YouTube, Twitter) have hundreds of millions of users.

Data mining is transforming the way one thinks about "crisis response, marketing, entertainment, cybersecurity, and national intelligence" (National Research Council, 2013). It is also transforming how one thinks about information storage and retrieval. "Collections of documents, images, videos, and networks are thought of not merely as bit strings to be stored, indexed, and retrieved but also as potential sources of discovery and knowledge"—although exploiting the potential requires "sophisticated analysis techniques that go far beyond classical indexing and keyword counting"—such as finding relational and semantic interpretations of the underlying phenomena (National Research Council, 2013).

Caveats. The potential of the big data approach is undeniable. At the time of its study, however, the committee did not yet see successful unclassified applications clearly relevant to deterrence and assurance, although it noted opportunities as mentioned in the later section on Content Analysis. Further, the committee noted that inquiry seems to be strongly data-driven without adequate grounding in theory and with "validation" often discussed only in statistical terms. The committee did not look into intelligence efforts, such as those of the National Security Agency (NSA), where the situation may be different.

SOCIAL SCIENCE ANALYTICS

Case Studies and Narratives

Some of the most important social science methods relevant to deterrence and assurance involve comparative case studies or the somewhat related approach of cultural narratives. Although not new, both are underused in DoD's work on deterrence and assurance.

Comparative Case Studies

"Structured, focused comparison of cases" (George and Bennet, 2005) can illuminate how deterrence, assurance, dissuasion, and compellence actions and messages have been handled in real-world crises. Scholars working with such diverse sources as memoirs, declassified archives, oral histories, public statements

[3] This discussion is based on a National Research Council report (2013).

and documents, and with secondary literature as well, describe with a high degree of fidelity and texture the context for and activities in cases, including cases in which the background of nuclear weapons played a role. It is of particular value to *compare* studies chosen to be different along important situational dimensions. Doing so converts descriptive explanations of case outcomes into analytic causal but contingent explanations: a form of inductive theory building rather than raw empiricism. It identifies the "real" factors that appear to have been at work (e.g., sometimes personal and emotional, sometimes political) rather than restricting discussion to easily measured abstractions (e.g., population or force ratios).

Caveat. The final history is never written. Case studies must be revisited as new information arises that alters the inferred story, to include perceiving how deterrence was attempted and how signals were perceived.[4] Comparisons and debates are important because results can depend on both methodology and assumptions.

Cultural-Narrative Case Studies

A narrative is a spoken or written account of connected events. Cultural narratives are about a society's ideas, customs, and social behaviors. Understanding them may improve deterrence and assurance by allowing better messages to be crafted for a particular population or leader. Narratives are defined by their sequence and consequences with events selected, organized, connected, and evaluated as meaningful for a particular audience (Riessman, 1993). They shed light on such aspects of culture as values, morals, and perspectives (Chay, 2013). Narratives are seen as produced by people in a specific social, historical, and/or cultural context, and as devices through which individuals represent themselves and the world around them (Griffin, 2013). An example of where narrative analysis may be useful for deterrence and assurance is when it reveals "sacred values," defense of which may cause behaviors that would appear irrational to those from another culture.

Narrative analysis includes *thematic, structural, interactional, and performative* aspects. Thematic analysis focuses on the "what"—that is, on the meaning rather than the language used. It looks across stories in different styles to find common elements of meaning. Structural analysis focuses on how a story is told—examining syntax, rhythm, and pattern of words and sounds. It is currently arduous for long narratives. Interactional analysis emphasizes the process of teller and listener—that is, the exchange between storyteller and listener; it usually requires transcripts of conversation. Performative analysis examines the method of transmission, including who is involved, who persuades, and who does the storytelling.

Caveats. Understanding narratives is unquestionably important (as has long been recognized by intelligence services), but even a valid narrative for a society

[4] See Gerson (2010) for an example mentioned also in Chapter 2.

may not be characteristic of how leadership will reason or act. To some extent, leaders choose among themes or even modify them (think of Anwar Sadat in 1977 or Vladimir Putin in 2014). It is also possible to detect a valid theme but exaggerate its importance in determining actions. It follows that narrative analysis is probably more valuable for identifying factors and *possible* reasoning patterns than in reliably predicting actions.

Related Methods

The committee considered a number of other methods that, broadly speaking, are in the same category as case studies and narrative but are not discussed here. In particular, the committee was briefed by William Casebeer of the Defense Advanced Research Projects Agency (DARPA) on a program concerned with narratives, neurobiology, and implications for subjects such as radicalization and messaging strategies. See particularly Post (2003), including articles by Margaret Hermann and others.

Content Analysis and Profiling

Content analysis is the systematic retrieval of contents from a picture or a text. The content may be fact or fiction and may be manifest or latent (obvious or inferred). It may be keyed to different units such as words, phrases, sentences, or paragraphs. The assumption in content analysis is that the material studied contains information about the source's state of mind or information. Content analysis draws on data from, among other things, dreams and diaries, feelings and thoughts, and behavior and events in human societies (McClelland, 1961; Carney, 1972; Holsti, 1969). As discussed later in this chapter under "Analysis Methods" and in much more detail in Appendix E, modern quantitative content analysis can be a powerful tool in developing and updating leadership profiles directly useful for deterrence and assurance.

Information retrieval more generally may be qualitative or quantitative and may be recorded in narrative, statistical, or visual formats. Related tools are ordinarily based on theoretical constructs that help interpret the results. Several constructs categorize behaviors in world politics. The basic categories of behavior are (1) types of words and deeds and (2) types of cooperation and conflict behavior. Evidence on the behaviors is retrieved from sources such as newspapers and other media. Trends are then observed regarding the variety, sequence, volume, and intensity of actor behaviors in interactions with others. Speeches and interviews are analyzed to retrieve thoughts, beliefs, emotions, and motivations (Post, 2003). Well-validated tools are available, some of them automated (Smith, 1992; Post, 2003; Young, 2001).

TABLE 3-2 An Example of a Taxonomy and Scale for Interactions

Conflict		Cooperation	
Deeds	Words	Words	Deeds
Force (–10)	Threaten (–5)	Approve (+1)	Yield (+6)
Seize (–9)	Warn (–4)	Consult (+2)	Grant (+7)
Expel (–8)	Demand/accuse (–3)	Request (+3)	Reward (+8)
Reduce relations (–7)	Protest (–2)	Propose (+4)	Agree (+9)
Demonstrate (–6)	Reject/deny (–1)	Promise (+5)	

NOTE: Numbers in parentheses illustrate values of escalation and de-escalation of conflict or cooperation behavior.
SOURCE: Data from McClelland (1972, pp. 96-97; 1968, p. 168).

Prominent examples in world politics use scales developed some years ago (McClelland, 1966; Schrodt, 1994; and Goldstein, 1992). All of these base their categories on word/deed and conflict/ cooperation distinctions. The automated descendants of these early coding schemes employ dictionaries of synonyms for various transitive verbs. They retrieve not only verbs, but also nouns representing the relevant subjects and objects of the verbs in the text. It is now possible to conduct a huge quantitative content analysis of electronic text quickly.

Table 3-2 illustrates a scale stemming from such work. Such a scale might describe evidence relating to escalation, de-escalation, or cooperation over a crisis period . The scale uses event categories from the World Event Interactions Survey (McClelland, 1972; see also McClelland and Hoggard, 1969). They distinguish cooperation and conflict by rankings along a continuum of words and deeds, with deeds ranked as more intense instances of cooperation or conflict than words. The scales used (−10 to 10, with protocols for assigning values) have been subjected to both conceptual and empirical scrutiny for reliability and validity (e.g., McClelland and Hoggard, 1969; Hermann 1971; Kegley, 1973; Beer et al., 1992). The assessments report good reliability except for some problematic distinctions among categories at the upper end of the cooperation continuum (Beer et al., 1992).

Scholarly controversies exist over whether these categories should be seen as measuring intervals, measuring ordinal rankings, or simply indicating nominal but independent categories. Thus, the methods may be seen as quantitative or qualitative (McClelland, 1983; Howell, 1983; Vincent, 1983; Beer et al., 1992), which affects the mathematical sophistication that can be used. However, even the more qualitative versions allow monitoring activities for changes in indicated trends toward escalation, de-escalation, or cooperation, and perhaps what actions may be expected of an adversary or ally (Walker et al., 2011; Walker, 2013). Again, see Appendix E for more details relevant to deterrence and assurance.

Caveats. Practitioners have varied skill—for example, in extracting valid insights in the midst of boilerplate and sometimes hypocritical prose. Also, certain kinds of evidence can be manipulated (a country may, for example, release materials intended to threaten and scare without the intention of action, or may release materials intended to soothe despite actual malintent).

Social Network Analysis

Sometimes deterrence requires understanding groups and networks rather than just individuals. An element of doing so is social network analysis (SNA). In the popular psyche the notion of tracing complex networks of social connections shows up in the common acceptance of the idea that any two people on Earth are separated by no more than six degrees of separation, as popularized in the Broadway play by John Guare and the popular Kevin Bacon game.[5]

SNA refers to an application of network theory to the study of complex, formal and informal social systems.[6] SNA views the links between actors as the "channels for transfer or 'flow' of resources (either material or nonmaterial)" (Wasserman and Faust, 1994, p. 4).[7] The unit of analysis is not the actor itself but the *network* that consists of the actors and the linkages between them. SNA can be applied to vastly different networks, such as national-leadership groups, graduates of military academies and exchange programs, academic researchers, or to church and neighborhood groups. Typically analysts begin an SNA analysis by constructing an adjacency matrix or a sociogram to visualize a social structure in which people or organizations are represented as "nodes" and the relationships or linkages as "edges" (see Figure 3-1). Linkages can be direct (e.g., brothers, sisters, coworkers), or indirect, as in a common demographic such as age or sex or some other shared attributes (graduation from the same college).

Once the network has been defined, metrics can be calculated to aid in analysis and interpretation. Centrality measures characterize the relative importance of a node in a network—for example, "degree centrality" which calculates the number of direct ties to a node; "betweenness centrality," which measures the relative importance of a particular node by how many other nodes it connects to; and

[5] To play the Kevin Bacon game, players search for the shortest connections between a chosen individual and the actor. For example, an individual's Bacon number would be 6 if his or her second cousin was Anne Bancroft, Anne Bancroft was in *Waking Ned* with Ian Bannen; Ian Bannen was in *Braveheart* with Mel Gibson; Mel Gibson was *in Bird on a Wire* with Goldie Hawn; Goldie Hawn was in *Housesitter* with Steve Martin; and Steve Martin was in *Novocain* with Kevin Bacon.

[6] Sociogram source: de Nooy et al. (2005, p. 5).

[7] Wasserman and Faust (1994).

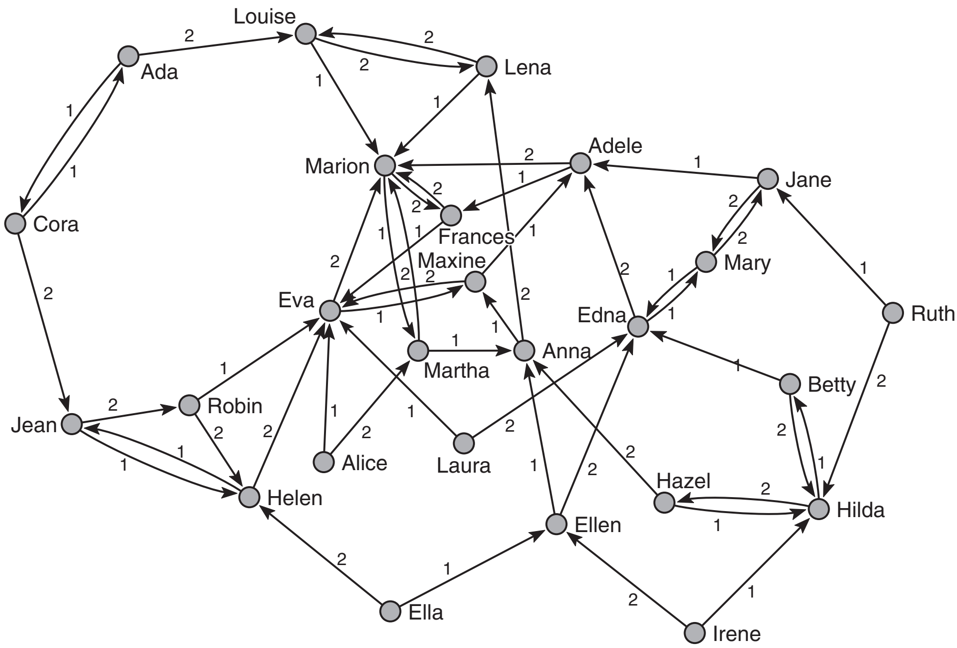

FIGURE 3-1 Nodes and edges in a social network. SOURCE: de Nooy et al. (2005), copyright 2005, reprinted with permission of Cambridge University Press.

"Eigenvector centrality," which measures a node's influence by the number of its connections while giving greater weight to high-value connections.

SNA has been widely applied in sociology and other social sciences. It has proved useful in applied settings such as law enforcement, threat finance, counterinsurgency, and counterterrorism. In the area of deterrence- and assurance-related assessment, SNA can be used to test models and hypotheses about relational structures or networks. It would be an appropriate tool for addressing questions of the following types: Which nodes (individuals, organizations, etc.) in a network are the most critical to its operation? What is the structure, density, and size of a human network? What is the nature of the power relations? How has a group gained and retained its power? How can a leader be influenced by threatening to or actually affecting those to whom he is linked and on whom he is dependent for power?

Caveats. The compilation and coding of network information can be long and tedious. Moreover, while relatively simple in concept, analytic interpretation of centrality and other measures requires knowledge and technical expertise. Also, SNA's scope is limited. It would not be an appropriate method to assess, for example, the substance of an actor's intention and world view, leadership style, decision-making style under threat or stress, or other nonnetwork-related attributes and behaviors.

QUASIEMPIRICAL SOURCES: GAMING AND COMPUTATIONAL MODELING

This section discusses important sources of what we have called quasi-empirical information in the categories of human war-gaming and computational modeling.

Human War-Gaming

Human war-gaming has been used for centuries in a variety of ways, as discussed in a book by Peter Perla (1990). The perspective and observations made here are more narrow, reflecting certain types of military war gaming conducted by the Services and major commands, sometimes through war colleges (Downes-Martin, 2013).

Seminar War-Gaming

The goal of a war game is to provide insights by identifying hypotheses for testing by other means. There are three main challenges when using seminar war-gaming within military organizations to explore strategic nuclear deterrence.

First, unlike tactical conventional kinetic warfare, there is no long history of understandable results with credible statistically valid data for activities related to strategic nuclear deterrence. War-game adjudicators therefore have no rules determining the possible outcomes between protagonist players' decisions. The second challenge stems from the first in that the need to develop rules at the time means that the adjudicators are de facto decision makers or players—even dominant players—something very different from their ostensible role as impartial referees. This suggests that war games dealing with strategic nuclear deterrence should collect data and information from adjudication teams as from traditional player cells. This is not usually possible because it would mean additional and time-consuming overhead, making it difficult to have an effective game within the usual one-week time period allocated by major commands for a war game.

A third challenge is that decisions made during game play are probably poor proxies for decisions that even the same players would make in real life.[8] Fortunately, strong evidence from psychological research, as well as observation of games, indicates that their beliefs about a situation and their reflexive decision-making styles and preferences are more stable, even when they are confronted with credible evidence.[9]

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[8] Jervis (2006, pp. 3-52); Wilson (2002); Pronin (2007); Nisbett and Wilson (1977, pp. 231-259).

[9] Ross and Anderson (1982, pp. 129-152); Ross et al. (1975, pp. 880-892); Anderson et al. (1980, pp. 1037-1049).

Observation 3-2. Effective War-Gaming. It is more fruitful to design war games to understand player *beliefs* and perspectives, than to treat decisions within games as reliable information. The focus should be on the *reasons* for decisions, the messages sent and received, and the interpretations and misinterpretation of messages.

If these reasons are understood, then it should be possible to embed the underlying belief systems in models, simulations, and analysis for subsequent research (see also the section on synthesis). Seminar gaming is also conducted in other settings, such as civilian think tanks. The purposes are then different, as are their challenges. In some cases, members of the adjudication team may reflect deep knowledge (sometimes from prior real-world experience) regarding how decision makers would reason and about possible political and economic consequences of decisions not so evident to more typical adjudicators. So also for members of the country teams. Even so, the games are likely to provide better insights about factors, considerations, and beliefs than about what decisions would actually be.

Lessons To Be Learned from War-Gaming

War games as practiced at the Air University and the Air Force Global Strike Command (AFGSC) in recent years have had some severe limitations. Annual end-of-the-year Air War College and Air Command and Staff political–military games have often not had the objective of representing weapons of mass destruction (WMD) play. Controllers have often outlawed early use of WMD because it would stop the game, thereby ruining the opportunity for participants to go through the learning of routines that are the purpose of the games. This may have communicated the wrong lessons on WMD play because of artificial restraints.

War games involving nuclear exchanges conducted by AFGSC may err in the opposite direction. These exercises usually begin with early use of nuclear arms and do not include decision makers who have political or diplomatic roles. Each exercise thus is a walk up the escalation ladder without remedy to diplomatic or political means of arresting the conflict. These games have also omitted use of chemical and biological weapons in conjunction with nuclear employment, even though possible U.S. adversaries have a combination of such WMD assets.

AFGSC games are designed to start with early nuclear use. Such games avoid the problems of the Air University games because nuclear weapons employment is not arbitrarily prohibited. Indeed, the games are designed to acquaint participants with the nuances of nuclear warfare. However, the lack of a means of achieving a diplomatic end to such conflict in games may lead participants to the dubious belief that they can play nuclear chess. This remains highly speculative since there exists no historical record by which to judge. *There is also no way to know if real decision makers in actual future crises and conflicts would act in reality as they act in games.*

Caveats. War gaming must be integrated with other methods of inquiry and analysis since such war games by their nature do not prove or validate anything; any specific war game is a single trajectory through the space of possible scenarios defined by the interactions of all players in a game. Even the broader insights gained from post-game "hot washes" discussing both a particular game and what might have been must be regarded as tentative. That said, they can be quite valuable. Further, players learn a great deal about the relevant strategic "chessboard."

Computational Experimentation

Significance

Computational experimentation systematically harnesses a causal model of a phenomenon to conduct "experiments" over much of the model's operating domain, generating substantial "data." In some problem domains (e.g., in some engineering applications), the model may be validated, in which case the data can treated as empirical. More relevant to this study is computational social science in which the model in question is afflicted with uncertainties of two primary types: (1) parametric (i.e., input uncertainty) and (2) structural (i.e., uncertainty about the model's content, such as completeness of its variables and the algorithms by which they interact).

Computational modeling will be discussed primarily in later sections relating to knowledge and theory development, but its data-generating role has become important with the advent of new technology, computer power, and conceptual approaches to analysis. This section discusses the vexing and cross-cutting problem of validation. Some of the points apply more broadly to validation of qualitative models as discussed in the next section.

Validation

Given the uncertainties typically associated with social-science computational models, a fundamental question is how they can be "validated" and what that should mean. A modest but thoughtful literature exists on this subject.[10] It is inappropriate to see the models as "predictive," as are models in the physical sciences

[10] See McNamara et al. (2011) and Bigelow and Davis (2003), which discuss validation for an analogous class of computational exploration. For results of an National Research Council (NRC) workshop, see National Research Council (2011b) and the unedited proceedings at http://sites.nationalacademies.org/DBASSE/BOHSI/DBASSE_071321. An earlier NRC report discusses the different classes of uncertainty (National Research Council, 1997).

and engineering. Even so, exploration with such models can yield valuable insights. A natural and common rejoinder is, What good is a model if it can't predict? How can the insights allegedly gained be valid? The answers begin with the observation that qualitative models have long been useful in all walks of life. For example, they may characterize the system, its parts, and the ways in which the parts interact with each other and the external environment. Even if the consequences of the interactions depend on unknown at-the-time details, the models may provide a structure for understanding the system and adapting to developments.

The word "may" applies because the model must be sufficiently solid "structurally," and there must be some understanding of the range of plausible values for the variables within it.[11] That is, the model must incorporate the most important variables at work—the right "factors." Also, the model must convey a roughly right sense for how the factors affect system behavior. Fortunately, and despite their notorious shortcomings, experts in a given subject area usually have a strong sense of what variables matter and some sense about how they interact qualitatively.[12] It is possible to "validate" their judgments by, for example, consulting different experts; conducting case studies to see whether the variables that they identify appear to have been important and whether other variables had been omitted; and evaluating the qualitative theories logically.

Caveats. Computational experimentation can be a good source of tentative insight about subtle possibilities, including possibilities against which deterrent strategies should hedge. If the models have sufficient structural validity and uncertainties can be bounded, exploratory analysis can yield nontrivial insights. Those, however, must then be assessed separately, as are, for example, potential insights from war gaming or experience.

FRAMEWORKS AND QUALITATIVE MODELING

In this section, we start with two subsections providing frameworks for thinking about deterrence and assurance. The subsequent subsections then describe particular qualitative methods for modeling or building theory.[13] Some of these discuss qualitative aspects of what are more typically seen as quantitative methods.

[11] A model can be useful even if based on assumptions known to be false. For example, a useful rational-actor model may claim that behavior will be *as though* reasoning followed rational-actor prescriptions (an argument first made by Milton Friedman).

[12] See Tetlock (2005 and earlier works).

[13] Whether a model is qualitative or quantitative is murky in both theory and practice. Included here as qualitative are models that may use numbers that are merely mapped from subjective measures such as "low" and that emphasize problem structure and logic rather than computations.

A Broadened Framework

Deterrence and assurance depend fundamentally on psychological matters. Those are often strongly affected by "objective" situational considerations, such as geography and relative power. However, to be deterred or assured involves a state of mind. As discussed in more detail in Appendix D, which draws on a rich multidisciplinary literature, it is useful to have a broad framework for discussing such issues.[14] The framework in Figure 3-2—for the simplified case of actor A and actor B—highlights a number of important concepts. First, the decisions the actors make (box in center) occur in an "external level" of context that includes the geopolitical situation, the relevant balances of power and threat, and so on. Second, decisions are ultimately made by some decision unit that may be a predominant individual, group, organization, or country and that may arrive at decisions based on any of a variety of processes characterized by rational-actor, limited-rational-actor, highly emotional, or other labels.

As if this were not enough complexity, the decision units of A and B are influenced by (note left column) systemic-, social-, and individual-level considerations. Here "social" includes type of regime and political system, standard operating procedures, factional interests, and related social psychology. "Individual-level" refers not just to the idealized thinking of the economic rational actor, but to psychological considerations such as beliefs, emotions, motivations, and personality traits.

Finding 3-2. Psychological Framework. Deterrence and assurance are largely psychological concepts. Thus, a proper evaluation of proposals for them will rely not only on the balance of military forces but also, whenever possible, on an understanding of the mindset and decision making of the adversary or ally.

As a corollary, the modern concept of "tailored deterrence" should be devised accordingly. As discussed at more length in Appendix D, a key element of this is how "messages" are passed and interpreted between or among parties ("messages" may range from diplomatic exchanges to signals accomplished with military or other actions). A substantial base of research describes just how complex and subtle such communication matters often are.

Finding 3-3. Tailoring Key Messages. To elicit the intended response, it is important for the sender to have methods and tools that can detect opportunities and send messages tailored to a recipient that is open (willing and able) to make a

[14] As discussed in Appendix D, the construct uses the levels of analysis of Waltz (1959), alternative images of decision making introduced by Allison (1969) and supplemented by Post (2003), and ideas from, for example, Campbell et al. (1960) and Kegley and Witkopf (1982) among others.

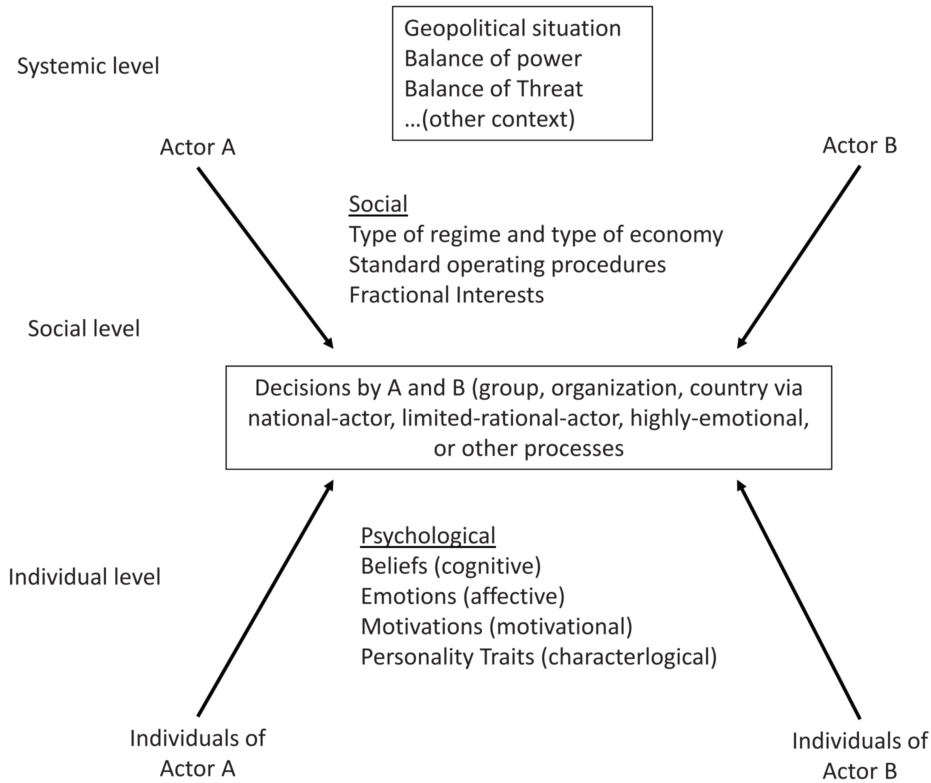

FIGURE 3-2 A broad framework for thinking about human decision making.

response based on available information rather than on motivational, affective, or cognitive biases in a deterrence or assurance situation.

This finding means that the deterrer needs to diagnose the situation, identifying the adversary's decision unit and elements within it, understanding when one or more elements is likely to be open or closed, what might be causing "blockages," how channels could be opened or open channels found, how messages of different types will be interpreted and how the likelihood of correct interpretations can be increased. Appendix D includes a relatively simple heuristic method (requiring analytic artistry, of course) for thinking through such issues.

Complex Adaptive System Theory

Figure 3-2 provides a kind of conceptual framework. An analytically richer scientific framework is provided by the theory of complex adaptive systems (CAS). CAS are usually described as hierarchical or nearly hierarchical collections of interacting entities that are adaptive in responding to each other and the external environment. Macroscopic system characteristics may "emerge" as a result of the interactions. Although CAS theory is quite general, it has been strongly motivated by such biological systems as the human body with its cells, tissues, organs, and functional systems. Most interesting social systems are examples of CAS, including a system of state and nonstate actors interacting in crisis.

A famous characteristic of complex adaptive systems is that—in some circumstances—small changes can have large and essentially unpredictable effects, sometimes with the system moving into one of two or more alternative states, to include peace or war. Describing a system in crisis this way is different from using a deterministic model that sees inexorable and predictable outcomes.[15]

CAS theory is a natural paradigm for work on deterrence and related matters and even for research on military matters more generally. Earlier NRC studies have urged DoD's modeling and analysis to embrace the CAS paradigm (National Research Council, 2006). Doing so should also be part of the basic education of analysts seeking to describe or understand phenomena such as deterrence.[16] Complexity thinking affects many of the other sections of this report, including that on computational modeling.

Caveats. As with many "new" and important subjects, CAS research is sometimes afflicted with breathless popular accounts, amateurish attempts to apply its concepts, and exaggerated claims about the usefulness of related models and the validity of their predictions.

Qualitative System Modeling

The subject of deterrence is both complex and "soft" because it is about the thinking and behavior of people influenced by myriad interacting factors. Qualitative system modeling can be quite fruitful in understanding situations and evaluat-

[15] Books by pioneers are still especially illuminating (Holland and Mimnaugh, 1996; Gell-Mann, 1994). Some texts on CAS and agent-based modeling are Bar-Yam (2003) and North and Macal (2007).

[16] See Robert Jervis on applying complexity theory to war-and-peace issues (Jervis, 1997a,b).

ing strategies.[17] It can have many of the virtues of system modeling generally: (1) representing the "whole," (2) characterizing influences, (3) representing interactions and feedback effects, and (5) conveying a coherent albeit complex story. In contrast with many quantitative models, however, these do not purport to predict or forecast—something arguably beyond the pale in the presence of deep uncertainties, as discussed later in the analysis section. The following subsections discuss three classes of qualitative model.

System Diagrams of System Dynamics, Bayesian Nets, and Influence Nets

MIT-style system dynamics is more fully described in a later section under computational modeling, but a key element is its use of causal-loop and stock-flow diagrams that convey a "system map" or "system view."[18] Somewhat analogous "influence diagrams" stemming from Carnegie Mellon research by Granger Morgan and Max Henrion serve similar purposes.[19] System Dynamics is especially good at representing dynamical developments in systems with feedback loops. The Morgan-Henrion style has advantages for uncertainty analysis, multiresolution modeling, and decision aiding.

Other approaches using diagrams for visual modeling are Influence Nets and Timed Influence Nets, which stem from earlier work in Bayesian inference networks and related influence diagrams (with a different meaning of the term).[20] Belief networks and related influence diagrams are directed graphical representations for models of probabilistic reasoning and decision making under uncertainty. They capture important relationships among uncertainties, decisions, and values. Applications of Bayesian-net and influence-net methods abound, many of them in risk-related subjects and some related to national security (Caswell et al., 2011). Bayesian-net analysis requires a great many input assumptions such as conditional probabilities. Influence nets use an approximation that greatly reduces this

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[17] The committee considered quantitative political science and was briefed on recent interesting work related to nuclear matters. However, such research has limited value for its purposes because the historical data are and hopefully will remain sparse, and such work is usually about correlations, not the causality that decision makers often care about. Approaches that combine in-depth case studies and quantitative analysis would probably have more potential (Sambanis, 2004), as concluded also in a study of social science for understanding intervention operations (Davis, 2011).

[18] Sterman (2000) is a text. Specialized software tools include STELLA (from ISEE Systems) and VENSIM (from Ventana Systems, Inc.). A broad discussion of system thinking is in Senge (2006).

[19] See Morgan and Henrion (1992), a textbook on uncertainty analysis. The associated software is Analytica, developed and sold by Lumina Corp. Its use of the term "influence diagram" is different from some decision-analysis subdomains, where diagram nodes have probabilistic meanings.

[20] A tutorial is available from the vendor for Netica, one of the tools available for such work at http://www.norsys.com/tutorials/netica/nt_toc_A.htm. A simple description from an authoritative volume is in Schachter (2007).

burden. An extension to "timed influence nets" has been used for some years in work at George Mason University, including simulation of crisis developments and deterrence.[21]

Factor Trees, Cognitive Maps, and Cognitive Models

Recent DoD-sponsored research introduced deliberately simpler diagrams, *factor trees*, which show the factors influencing something of interest at a slice in time, such as whether an individual will become a terrorist or whether a population will support an organization that uses terrorism. [22] Factor trees have proven effective for interdisciplinary discussion involving social scientists, officials, and military officers. They have been used in both unclassified and highly classified work. Factor trees can be turned into modular computational models that exploit more social science knowledge. However, because of uncertainties, they should be used for exploratory analysis, as described in the later section by that name, rather than forecasting.[23]An example, Figure 3-3, shows a factor tree for public support for insurgency and terrorism. The structure of this qualitative model was developed in one project and then subjected to validation testing in a study using new case histories involving al-Qaeda, the Taliban in Afghanistan, the Kurdistan Workers' Party (known by its Kurdish acronym, PKK) in Turkey, and the "Maoists" in Nepal. The validation testing was encouraging; it led to modest refinements and sharpening but nothing new structurally.[24] The factor-tree approach should be directly useful in modeling deterrence and assurance issues.

Other qualitative diagram-based methods also deal with the thinking of individuals and groups. One method is cognitive mapping, as in the work of Robert Axelrod[25] and subsequent efforts.[26] A different kind of cognitive map appears in several strands of British work, including some that use such qualitative extensions of game theory as hypergames and drama games, which apply to problems involving confrontations and misperceptions. Participant may effectively be "playing

[21] See Levis et al. (2010) and earlier work referenced therein. Some of the Wagenahls-Levis work supplemented human play in war games at the Naval War College. SAIC (now Leidos Corp.) has developed proprietary tools called SIAM and Causeway for applications to government and industry, including crisis simulation work. An overview is available at http://www.inet.saic.com/inet-public/inet-intro.htm.

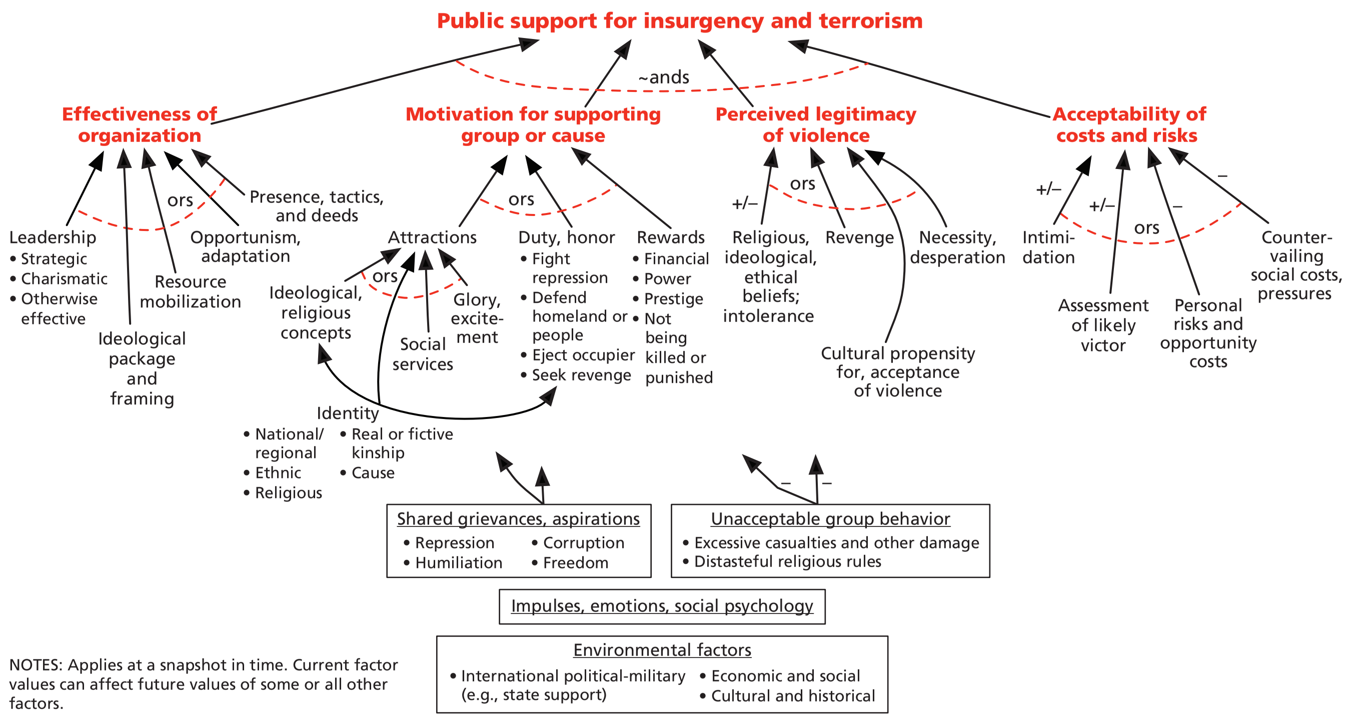
[22] Davis and Cragin (2009).

[23] Davis and O'Mahony (2013).

[24] Davis et al. (2012).

[25] Axelrod (1976).

[26] The term "cognitive map" has many meanings with related streams of literature. It did not seem appropriate to discuss most of them here.



NOTES: Applies at a snapshot in time. Current factor values can affect future values of some or all other factors.

FIGURE 3-3 Factor tree for public support of insurgency and terrorism. SOURCE: Davis et al. (2012), adapted with permission by the RAND Corporation.

different games" and thus not even be sharing the same "gameboard," emotions, and other complications—all relevant to deterrence research.[27]

More specific to deterrence, simple *qualitative cognitive models* expressible in diagrams and hierarchical decision or outcome tables have been used to understand the potential reasoning of adversaries such as Saddam Hussein in 1990-1991,[28] Kim Jong Il in the mid-1990s, and terrorist leaders in recent times. These can aid coherent discussion of *different* ways in which adversaries may reason and aid development of related hedged strategies. Such hedging is important because best-estimate assessments of adversary thinking have often been quite wrong (a problem highlighted in Chapter 2).[29] Such cognitive models can be informed by a combination of strategic thinking, personality profiles, as discussed later in this chapter and Appendix E, and additional inputs from regional/cultural experts.

Caveats. As with other methods, the value of qualitative modeling depends on the particular modelers and analysts, their access to relevant information, and exposure to peer review. Considerable knowledge and sophistication are necessary, even though some of the methods appear simple.

Qualitative Game Theory

Game theory has long been important background for strategic thinking and practice with the basic concepts providing insights and language, such as Prisoner's Dilemma or Chicken. These are useful even in real-world problems that are far more multidimensional and otherwise complex than can be dealt with convincingly by mathematical game theory. The committee does not review game theory here, instead regarding it as part of the baseline of methods. As discussed in Appendix D, however, it is useful to highlight certain advances in qualitative game theory that are valuable and simple enough to be understood and used, if only for background. Appendix D illustrates these by discussion of advances in the 2×2 "ordinal" game in which players have only two strategies and four possible qualitatively expressed outcomes to consider. This is by contrast with having more options, quantitative evaluations, and the need to make sometimes tricky mathematical calculations.

The primary innovations with significant value for drawing insights include using (1) sequential games in which the sides alternate in their moves until play stops and (2) allowing for asymmetric and perhaps incorrect information. In contrast with traditional game theory, results are seen (realistically) to be very dependent

[27] See British work (Bennett, 1985), including some applied to understanding and succeeding in operations other than war (Howard, 1999).

[28] These grew out earlier work that built massive "analytic war games" with optional agents for decision making by U.S. or Soviet leadership. One conclusion was that the cream could be skimmed in representing adversary reasoning with drastically simpler qualitative models.

[29] See National Research Council (1997), which drew on previous work (Davis and Arquilla, 1991).

on where the game begins, what sequencing occurs, and who has the "move power" to end the game. It follows that game outcomes include some worrisome situations that are not the familiar Nash equilibria of static game theory: they reflect dilemmas analogous in significance to, say, the Prisoner's Dilemma or the game of Chicken. Game theoretic methods are valuable not only because of their insights but because, despite their simplicity and unpretentiousness, they add important aspects of realism that can readily be communicated and learned.

COMPUTATIONAL MODELING

Earlier discussion covered some of the same tools but emphasized their qualitative-modeling aspects. Here the discussion is about computational capabilities.

System Dynamics, Bayesian Nets, and Influence Nets

MIT-style System Dynamics, mentioned above, was introduced about a half-century ago (Forrester, 1963, 1969, 1971) and is well described by a modern textbook with examples and problem sets (Sterman, 2000). It was remarkable in part for taking on "soft" social problems of great significance and bringing to bear mathematical and computer methods familiar from other disciplines. One stumbling point was *Limits to Growth* (Meadows, 1974), a book that was contentious for both good and bad reasons. The book and the related controversy, however, stimulated constructive counterstudies and considerable progress in understanding how to use model-based analysis and how to improve the modeling itself (Greenberger et al., 1976). A 30-year retrospective is a well-regarded cautionary piece about the potential for societal "overshoot" due to the interactions between human development and other matters such as sustainability.[30] System Dynamics has been used extensively over the years and the approach remains vibrant. Other studies have used somewhat similar methods but different modeling tools.

A good deal of computational modeling has been used for defense work, much of it DARPA-funded science and technology.[31] Some has dealt with the road from crisis to conflict and escalation, as in work briefed to the committee by Alex Levis and Kathleen Carley from George Mason and Carnegie-Mellon universities. They used multimodels that combine timed influence nets, agent-based modeling, and system dynamics. Somewhat analogous multimodeling research is ongoing at other universities.

[30] The Australian government's Commonwealth Scientific and Industrial Research Organization published a balanced review that compares actual developments over the 30 years with scenarios examined in the original work (the work held up rather well).

[31] See Popp and Hen (2006).

Caveats. If studies involve major uncertainties, then models should be used for exploratory analysis, as discussed in the later section on the subject, rather than using just best-estimate cases and some excursions. Another caution is that the models in question often have buried structural shortcomings, as in assuming independence of events and ignoring some nonlinear effects. Finally, it is not customary as yet for such models to undergo the substantive peer review that would be necessary in strategic applications. So far, studies have often been better in their computer science than in the depth of their social science. Hopefully, that will change and there are great opportunities to be exploited.

Game-Structured, Agent-Based Modeling

Example from the 1980s

Lessons can be learned from a game-structured simulation that was developed in the Cold War as the RAND Strategy Assessment System (RSAS).[32] This was a global analytic war game covering conventional war through general nuclear war. It allowed for independent decisions by NATO, the Warsaw Pact, and individual nations such as Britain and France with their independent nuclear deterrent. Human teams or models (agents) could be used interchangeably.

Rather than trying dubiously to "optimize," the agents used heuristic artificial-intelligence devices. Higher-level models drew on escalation-ladder structures and the current and projected status of combat and conflict levels to make decisions. Operational war plans were modeled with what in artificial intelligence circles were called branched scripts (what a commander would call branches and sequels).

The RSAS had *alternative* versions of the top-level agents to embody different "mindsets." This innovation was significant because then, as today, experts argued about how the sides' leaderships would reason and act. Further, no one knew. In stereotype, one Red model was a determined "warfighter" reflecting Soviet military doctrine; another reflected the more pragmatic image many Sovietologists had of political leadership. Both models intended, however, to make rational decisions. Thus, the agents departed from their stereotypes: The warfighter might compromise and the "pragmatic" model might escalate.

[32] See Davis and Winnefeld (1983) and Davis (1989). "Game-structured" means that the model was organized around decision-making entities (agents) as in a human war game. One simulation run was analogous to a single human war game. Only some game-structured models are "game-theoretic." For example, some combat models have the simulated commanders allocate their air forces and even ground forces so as to *optimize* simulation results, taking into account that the adversary model might be trying to do so also. See Hillestad and Moore (1996). Such methods are valuable for analysis dominated by physical phenomena such as conventional combat.

As one relevant example from 30 years ago, RAND conducted experiments with limited nuclear options. Blue had a model of Red, which had a simpler model of Blue, which had an even simpler model of Red. In some cases, Blue would use a limited nuclear option to "re-establish deterrence," as in NATO doctrine. Red, however, would perceive the act as Blue having initiated nuclear war and would immediately engage in all-out general nuclear war. In other runs, depending on details and model, Red would de-escalate or continue even though not having "won." This study cast doubts on NATO's concepts and plans for nuclear use shortly before collapse of its conventional defenses (Davis, 1989), suggesting that such late use might be especially ill-advised. The insights were similar to those from sensitive high-level U.S. war games conducted in the 1980s (Bracken, 2012). Another observation drawn by RAND was that many (most?) of the insights to be gained can be obtained with simpler models and even simpler methods, such as described elsewhere in this report (e.g., qualitative cognitive modeling).

Observation 3-3. Alternative Adversary Models. Because of irresolvable uncertainties, disagreements among experts, and the need to open decision maker minds to non-best-estimate possibilities, it is important to use *alternative* adversary models rather than relying on best estimates, however carefully developed.

This finding reinforces the need for leadership profiles as discussed later and in Appendix E, but with some tension because it emphasizes having alternative assessments.

Modern-Day Options?

Analogous game-structured computational models could be built today with more advanced technology.[33] The value of such work would still depend on the models representing deep knowledge of political and military issues and of human and organizational decision making. They would be even more complex because of needing to represent economic instruments of power, the interaction of multiple nuclear powers (some with chemical and biological weapons as well), and the consequences of precision weapons and the cyber and space domains. The classic escalation ladder could no longer be used as an organizing principle because the types of war have become intermingled. Such an enterprise would be a daunting and sizable undertaking, as was the 1980s effort, which stemmed from

[33] Relevant technologies include agent-based modeling, multimodeling that combines models of different types (Fishwick, 2007), more powerful graphics, and mechanisms for exploratory analysis.

a recommendation of the Defense Science Board and was funded by the Secretary of Defense's Office of Net Assessment.[34]

Caveats. If one were contemplating a modern-day construct, it should be noted that, while the RSAS was technically successful, afforded insights, and became the basis for a number of studies, it proved too difficult for inside-government work, despite heroic efforts to make it comprehensible and modular (Hanley, 1991). The reasons included the sophistication needed, personnel turnover, and something more subtle: Effective use required independent thinking against the grain of conventional wisdom and with not too much respect for "best estimates." Such thinking is often not the strong suit of military or other government organizations.

Modeling of Limited Rationality

A cross-cutting issue in computational modeling (and, also in the qualitative modeling described earlier) is the type of reasoning assumed. Regrettably, too many modern computational models give their agents simplistic rational-actor algorithms. Fortunately (see also Chapter 2), the rational-actor model has been embellished and other steps taken to go beyond it by focusing on, for example, perceptions rather than reality, recognizing that utility functions (to the extent that utility functions exist and are stable) vary across individuals and groups and are often poorly understood by others, that individuals have only limited rationality, that agents in multiagent situations will assess their power positions relative to others and adjust their positions accordingly to improve their overall prospects, and that risk aversion is an important consideration.

One element of such work has been to represent rather predictable behavioral considerations demonstrated in experimental psychology[35] and discussed by some political scientists. [36] The most well-known consideration is described as "prospect theory," which asserts that a decision maker evaluates options differently depending on whether he is in the "domain of losses" or the "domain of gains." This explains why deterrence is easier than compellence: The perceived value from possible gains is seen as less than the perceived value of maintaining gains already achieved. Some such work is cross-cutting and discusses how rational-choice theory can perhaps accommodate prospect-theory effects (essentially by recognizing that utilities are

[34] One modern game-structured simulation is the British Peace Support Operations Model (PSOM), used to support operations in Afghanistan. It was not designed to deal with nuclear issues or deterrence. See Body and Marson (2011) and accompanying articles.

[35] The work was pioneered by Daniel Kahneman and Amos Tversky. See Kahneman's Nobel address (Kahneman, 2002) and a recent accessible synthesis (Kahneman, 2011).

[36] See, for example, Jervis et al. (1985).

not stable and correcting for predictable situation-dependent effects, including risk-taking).[37]

In contrast to thinking in the 20th century, it is now increasingly recognized that the rational-actor model is not always appropriate, even as a normative standard. That is, it is not only not descriptive; it is sometimes not appropriate. This stems from recognition of the value of "naturalistic," heuristics-driven human adaptivity using cognitive short cuts.[38] Some of the literature discusses the need to synthesize the perspectives of rational-analytic and naturalistic reasoning, emphasizing that both classes have their place (Davis et al., 2005). Someone in the heat of battle should rely on heuristics, while someone in peacetime should take the time for more deliberate and rational-analytic reasoning. However, the heuristics should reflect knowledge informed by rational analysis and rational analysis should allow for creative thinking, which is often intuitive. This balanced perspective has recently been described by Kahnemann (2011), dissipating earlier controversy between the heuristics-and-biases and naturalistic schools.[39]

Observation 3-4. Modeling and Limited Rationality. Both qualitative and computational modeling in support of deterrence and assurance should incorporate aspects of "limited rationality" and even more strongly emotion-driven behaviors.

ANALYSIS METHODS FOR DECISION AIDING

The committee did not review methods seen as part of the baseline.[40] A number of advancements, however, are relevant to modern-day analysis of nuclear-force issues.[41] What follows highlights four methods with direct implications for deterrence and assurance studies. They deal with (1) leadership profiling), (2) analyzing

[37] One often-cited paper was specifically undertaken to cross the intellectual divide between rational-choice and behavioral-theory perspectives (Bueno de Mesquita and McDermott, 2004). The article appears in one of two special issues of *Political Psychology* devoted to related matters (Volumes 2 and 3 in 2004).

[38] See Klein (1999, 2006a,b), Gigerenzer and Selten (2002), and Suedfeld et al. (2003).

[39] See Bueno de Mesquita (1997); National Research Council (2011a) and references therein, and DoD work with the Senturion model (Abdollahian et al., 2006).

[40] Examples include operations research, systems analysis, statistics, and classic game theory as described in, for example, Powell (2005), Washburn (2003), and Poundstone (1992). The first two are texts; the last describes game-theory history and its implications for arms races.

[41] One example showed attacking mobile launchers has more leverage than intercepting missiles in flight (Shaver and Mesic, 1995). A second example showed that optimizing resources to protect infrastructure has a different character when the infrastructure is large and attackers are limited (Brown et al., 2005). Third, optimizing to assure resilience involves sequential non-zero-sum games with three phases: (1) initial defense preparations, (2) an attacker observing the preparations, and (3) the postattack adapting with what remains.

receptivity of adversaries, (3) exploratory analysis and robust decision making, and (4) strategic portfolio analysis. The method of sequential ordinal games discussed earlier (under qualitative game theory) is also relevant.

Leadership Profiling

Motivation Approaches

As discussed in Chapter 2 and earlier in this chapter, deterrence and assurance depend strongly on the psychology of those to be influenced. It follows that we should be quite interested in developing profiles of both adversaries and allies. What profiling methods are available? As discussed in considerable length in Appendix E, drawing on substantial literature, two distinct approaches exist (each with many variations). The first may be seen as top-down and is based on developing a subject's psychobiographical background and then using the insights to assess current circumstances. The second approach may be seen as bottom-up and draws on more proximate evidence to infer characteristics such as openness and risk-taking propensity. This second approach emphasizes *quantitative content analysis*, as also discussed briefly early in this chapter. Methods have been developed and substantially refined that allow significant inferences to be drawn from, among other things, speeches, interviews, news conferences, diplomatic exchanges, and (in principle) classified documents. Changes in the inferred behavior over time can be particularly valuable. Appendix E describes both approaches in moderate detail and illustrates them by working through the example of Saddam Hussein, on whom a great deal of peer-reviewed research has been published illustrating the approaches.

Selected Observations

When decisions are made, psychological and social processes act as causal mechanisms of cognition, emotion, and motivation, which Ledoux (2002) calls the "trilogy" of the mind. Contemporary neuroscience focuses on how the brain's physiology generates these mechanisms (Schafer and Walker, 2006: 49, n. 2; see also Ledoux and Hirst, 1986). In this model, the brain sends and receives messages along neural networks containing information in the form of cognitions, emotions expressed as feelings, and motivations directing action (Ledoux, 2002).

Learning and adaptation reflect such stimuli and information stored in the brain: they are emergent properties of human decision-making. Beliefs and belief systems, in turn, reflect these properties as higher-level and relatively conscious knowledge networks that are activated and modified by such environmental stimuli as threats or promises, These knowledge networks are linked with more primitive, lower level, unconscious elements of the trilogy outside the full awareness of the decision maker (Schafer and Walker, 2006, pp. 29 and 30). Observing the operation of these networks is difficult even if one has access to the decision maker and, certainly, if one does not (Schafer, 2000; Schafer and Walker, 2006).

While it is difficult to access and then assess the decision-making processes of a single leader, it is not impossible. The "at a distance" approach in political psychology infers subjective thoughts, emotions, and motivations of leaders and groups from the language that they use to express them. The assumption is that these sentient features of an individual or group can be modeled and tested (measured repeatedly) for accuracy with the aid of this information. These efforts yield a deeper understanding of the system of interest and its causal mechanisms. They may enable some predictions about future behavior under different assumptions about its evolving relationship to other objects. Fortunately, much can be done, as described in Appendix E.

Finding 3-4. Tailored Deterrence. The methods of content analysis and leadership profiling in conjunction with other methods have the potential to help meet requirements of actor-specific knowledge for a strategy of tailored deterrence. An alliance among content analysis, leadership profiling, abstract modeling, and gaming and simulations as a suite of methods is possible in order to solve the complex problems associated with studying the decision-making dynamics of single groups and multiple autonomous actors as decision units.

Understanding and Affecting Receptivity to Messages

As discussed earlier in "Content Analysis and Profiling," an important aspect of tailored deterrence must be understanding whether and how adversaries and allies receive "messages." The need to so has long been understood, but modern social-science methods provide a number of valuable ways to help. These are discussed in more depth in Appendix D, which includes a heuristic model (Figure D-2) that can be used artistically to diagnose the receptivity of the target, differentiating among different elements within the target, and to then identify priorities for "unblocking" channels when blocks exist (as is common). Although systematized and based on extensive theoretical and empirical scholarly research, the tactics and stratagems of the method relate well to real-world concepts familiar (if less systematically) to diplomats.

Exploratory Analysis and Robust Decision Making

With roots back to the early 1980s, a new approach to uncertainty analysis has evolved and been applied in many studies on defense planning, private-sector strategic planning, and social problems such as climate change and water management.[42] The approach deals pragmatically with deep uncertainty[43] by better understanding which such uncertainties matter most and where it is feasible, affordable, and fruitful to build hedges into plans, to prepare for inevitable adaptations, or both. The approach calls for exploratory analysis and seeks strategies that will be effective in any of a broad range of futures, although not optimal for any one of them. The methods are highly relevant to deterrence, assurance, and related matters where uncertainties loom large.

The concept of exploratory analysis is seemingly straightforward. If one has a good model representing the problem, but with the variables highly uncertain, then to test strategy options, one should want to know how they would perform throughout the entire scenario space or case space implied by the uncertainties. This goes far beyond sensitivity analysis around a standard case. A good strategy is one that would likely do well for much of the possibility space. Such a strategy would exhibit "FARness"—that is, it would be flexible, adaptive, and robust in the sense that it could accommodate changes of mission or objectives, changes of circumstance, and adverse shocks.

Modern methods allow such exploration, especially if the model is designed with two or more levels of resolution, in which case broad and comprehensible exploration can be made first, followed by more selective exploration of individual issues in more detail. "Scenario discovery" methods have the computer search for regions of case space that are, for instance, favorable or unfavorable.

Caveats. The value of exploratory analysis depends on knowing the primary factors, bounding uncertainties, and making judgments about what portions of the possibility space to plan for (which might be constrained by budget, technology, or plausibility). Tendencies to treat quantitative versions of such analysis as rigorous should be resisted and details of such uncertainty-sensitive analysis should be kept "down in the ranks," with higher-level discussions being simpler, more nearly qualitative, and unpretentious. The greatest value is in suggesting practical ways to cope with uncertainty with reasonable hedging and preparation for adaptation. If uncertainty analysis is obtrusive or complicated, it can become paralyzing or appropriately off-putting.

[42] See Davis (2014), a review (Davis, 2012), Lempert et al. (2003), and a website on robust decision making, http://www.rand.org/topics/robust-decision-making.html.

[43] Deep uncertainties (a term apparently introduced by Kenneth Arrow) are those that cannot be treated fruitfully with probabilistic methods because, for example, we don't understand the phenomena, we don't know all the factors, or we understand the phenomenon and have the factors but not their distribution functions (Lempert et al., 2003). Deep uncertainty incorporates what has sometimes been called future-scenario uncertainty.

Strategic Portfolio Analysis

"Strategic portfolio analysis," as the term is used here, is an approach to analysis with the following features:[44] (1) a focus on aiding policy makers; (2) multiple incommensurate criteria, some of them soft and in tension; (3) visual displays facilitating qualitative and quantitative discussion and debate; (4) the ability to examine issues at different levels of detail, and (5) confronting deep uncertainty and, often, disagreement among policy makers, when establishing strategy and allocating resources.

It has a metaphorical relationship to financial portfolio analysis and is logically just another example of multiple-criteria decision analysis. Its character, however, is different from that of most such methods. It is much less about solving a mathematical problem (e.g., "optimizing") than discovering—amidst strategic uncertainties and disagreements—acceptably balanced strategies that attend adequately to the multiple considerations, in part by hedging. In a defense context, criteria may include acceptable predicted results for test-case scenarios stressing different aspects of capability; dealing with various types of risk and up-side potential; and costs.

Decision makers see option comparisons expressed with policy scorecards showing how well the various options perform by different criteria. This is the level at which strategic decision is encouraged because, for strategic problems, it is seldom that there are well-defined a priori "weights" for the different criteria or that prudent decisions will correspond to taking linear-weighted sums. To the contrary, policy makers contemplate the assessments, ponder, discuss and debate with peers to "discover" their objectives and values. They think about balance and hedging because they must pay attention to *all* objectives. Further, they must deal with uncertainties and strong disagreements.[45] Policy-maker review can include interactive probing to understand in more detail underlying assumptions leading to demands for refined options and criteria and guidance about balance. Such iteration can be rapid rather than requiring repeated extensions of lengthy studies.

It then becomes possible to construct a composite measure of option effectiveness. The de facto "utility function" involved may turn out be nonlinear and is a *product* of decision making rather than an input. Since it reflects prior iterative discussion, it can be very helpful in constructing better-crafted composite options attending to the multiple criteria. As an example for nuclear forces, a composite option might include adjustments in force structure, force posture (e.g., forward deployment or routine deployments), weapons mix, and changes of employment

[44] For highlights, see Davis (2014), which includes references to more detailed work and a related tool.

[45] This type of thinking about "balance" was particularly evident in the speeches and actions of Robert Gates when Secretary of Defense.

strategy. These adjustments might be tested for deterrence in scenarios with different assumptions about circumstances and adversary mindset, and for deterrence with different assumptions about what allies find reassuring. New methods exist for considering a vast range of possible composite options and then filtering to retain those that could plausibly meet decision-maker criteria.

Consistent with the general emphasis on coping well with uncertainty and disagreement, cost-effectiveness analysis treats effectiveness and costs as uncertain. Further, it evaluates options using different "strategic perspectives" to highlight how disagreements do or do not affect the relative attractiveness of options. For strategic forces, such alternative perspectives may amount to different relative emphasis on, say, modernization, current operations, robustness of deterrence, reductions of weapons, regional stability, and nonproliferation objectives. Overall, the method is useful for integrative strategic analysis and debate. Its strengths are framing issues and providing insights about balance across multiple objectives, thereby influencing resource allocation.

Caveats. Some aspects of strategic portfolio analysis are familiar and seemingly straightforward. In practice, developing the appropriate structures to support vigorous strategic-level debate and decision is difficult—in part because it requires confronting sensitive uncertainties and disagreements, and raising options and considerations that are contrary to prevailing thought. Useful versions may be impossible without strong support from top policy makers insisting that that the sensitive matters be addressed. In the corporate world, this is sometimes accomplished with outside strategic consultant companies enlisted by top corporate officials.

OPPORTUNITIES FOR SYNERGY ACROSS TOOLS, METHODS, AND APPROACHES

Opportunities exist for synergy among, for example, human gaming, qualitative and computational modeling, historical studies, and game theory—traditionally separate activities. A synthesis would improve the quality of knowledge. As an analogy consider that one lesson from the hard sciences and engineering when dealing with complex systems is that the model becomes the centerpiece of knowledge with experimentation used to test, falsify or affirm, and/or calibrate the model—but with no illusions about it being possible to base reasoning and decision making on experimental data per se because the necessary data cannot be obtained or maintained. The model must then become the workhorse for aiding decision. As a result, experimentation is designed to test the model wisely. Rather than squandering tests on circumstances for which the model can reasonably be expected to be accurate, the experiments are focused primarily where they might yield new information about serious inaccuracies, random instabilities, or magnitudes of effects.

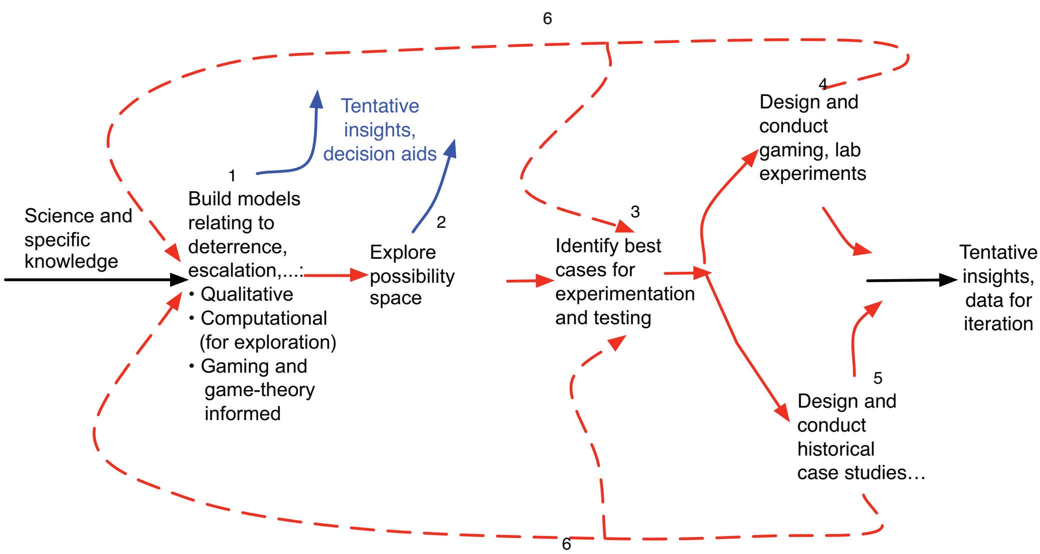


FIGURE 3-4 Synthesis of modeling and gaming approaches.

Figure 3-4 illustrates a concept that could be brought to bear in advancing the analytic study of deterrence-related issues. Some of its elements have precedent, but—overall—Figure 3-4 suggests a radically different approach to inquiry. It assumes that

1. An initial qualitative model is constructed drawing on the best social science, using both qualitative and quantitative methods and reflecting lessons from gaming and game theory.
2. A computational version is used for broad exploration.
3. Test cases are identified for more detailed experimentation, testing, and supportive research.
4. Such research is conducted using, among other things, human gaming, red teaming, and laboratory experiments (say, on behavioral matters), and also traditional social science methods such as comparative case studies.
5. Research results are folded back into the science and models with the process iterating (the time ordering is somewhat misleading, since knowledge building respects no particular sequencing).

Along the way, insights and data can be used (blue arrows pointing outward) as necessary, albeit with humility.

The schema of Figure 3-4 is not unreasonably ambitious; it is merely a construct for more systematic investigations of a sort that we know from experience are possible but that do not occur routinely or consistently.

Caveats. The caveats applicable here include the accumulation of caveats of previous sections. It should also be recognized that the kind of agenda envisioned in Figure 3-3 is challenging and difficult. It should be seen as a continuing community-wide idealization rather than, say, the sketch of a single study.

Observation 3-5. Fostering Cross-Domain Collaboration. Perhaps the most important next step in methods relevant to deterrence and assurance would be organized support for *cross-cutting* work drawing on the tentative insights and analysis from such disparate domains as human war-gaming, qualitative sequential games, simple cognitive modeling, leadership profiling, computational modeling, history, and other sources. Much can be gained by encouraging and "forcing" the related tribes to deal with each other.

This finding should *not* be interpreted as recommending some grand integration in a comprehensive model. An effort to accomplish that would almost certainly fail. The image should instead be one of cross-cutting work to develop better insights and analysis.

CONCLUDING REMARKS

This chapter has provided brief overviews and pointers to the literature of the many methods that can be brought to bear in studying deterrence and assurance in the years ahead. The topics discussed represent the committee's assessment of which methods considered have the most value for deterrence and assurance work.

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4

The Recommended Way Forward

In some respects, nuclear deterrence and assurance are now more complex than during the Cold War. Deterring a new set of nuclear-armed or potentially nuclear-armed adversaries while also assuring threatened allies requires continuous and informed balancing of both objectives. As current nuclear nonpeers emerge as near-peers or peers, they may not act as we expect. The nonpeer states that currently possess nuclear weapons and who are developing them are often ruled by regimes difficult to penetrate and about which decision-making dynamics are difficult to divine. Planning for the future must accommodate the uncertainty associated with the transformation of regimes from those that are staunch adversaries to those that may be tomorrow's allies. The situation is further complicated by the need to address the possibility of surprise in areas of technology or unforeseen changes in equipment effectiveness. Finally, because research addressing deterrence and assurance has declined since the end of the Cold War, the conceptual basis for developing and improving U.S. strategy and for equipping forces may not be as robust as it once was.

In Chapter 3, the committee reviewed and assessed tools, methods, and approaches (collectively referred to henceforth as "methods") that might be used to improve our understanding of how nuclear deterrence and assurance may work or fail in the 21st century and the extent to which such failures might be averted by proper choice of nuclear systems, technological capabilities, postures, and concepts of operation for U.S. nuclear forces. The committee had background in and was briefed on current analytics efforts. It concluded that while methods are important, the key to high-quality analysis in support of nuclear deterrence and assurance is qualified people who have extensive experience in the nuclear deterrence and assurance domain as well as in the relationships of nuclear options to general deterrence and assurance. The committee identified two types of methods that should be emphasized because of their relevance to the added complexity and uncertainty inherent in a deterrence and assurance environment that contains a more and more diverse set of nuclear adversaries. These are methods for (1) gaining insight into different styles, modes, and motives of an actor's decision making (discussed in Chapters 3, Appendix D, and Appendix E) and (2) dealing with "deep uncertainty" (discussed in Chapters 2 and 3). The committee also points out the need for analysts to be conversant in and use a suite of analytic methods, as well as the promise of hybrid methods in which different tools and methods, or the results of different approaches, are integrated—for example, using human gaming to inform quantitative modeling, as discussed in Chapter 3.

In considering how the Air Force should best approach deterrence and assurance analyses, the committee developed a top-level framework, primarily as a basis for categorizing these tasks and associated requirements for methods. Conceptually, the framework is straightforward. The reality is that the Air Force analytic community is not resourced to perform the analyses identified in this framework, many if not most of which require a whole-of-government perspective.

At a conceptual level, deterrence and assurance proceed through a sequence of steps, beginning with characterization of the situation or scenario involving potential actions adverse to the interests of the United States. That characterization leads to the identification of alternative U.S. objectives and then a characterization of the players in terms of their objectives, constraints, and values. Because of uncertainties associated with this characterization, alternative characterizations would ideally be constructed. The next step consists of determining feasible response options in the context of available capability and legal and political constraints, followed by the construction and assessment of a set of integrated, well-hedged, whole-of-government options, the choice of initial actions and the execution of a strategy, observing and adapting as the situation unfolds. It is within this context that the Air Force fulfills it deterrence and assurance mission. The subject of this study was analytic methods used to support Air Force decisions as it organizes, equips, and trains to meet its responsibilities in deterring adversaries and assuring allies.

The committee developed and applied criteria for evaluating methods. No candidate stands out alone. For example, methods related to actor-specific modeling and deep uncertainty have matured over the last two decades and are particularly relevant. Qualified analysts will, based on broad knowledge and expertise with the spectrum of available methods, select and apply those which are most appropriate. For many analysis tasks, a suite of methods will be the sensible and preferred tactic. As noted above in examining the current analysis efforts in nuclear deterrence and assurance the committee observed that analysts were doing a remarkable job given the resources available. The community makes excellent use of classic analytical methods. It has begun to address the challenge of actor-specific knowledge, but it is not currently prepared to fully exploit developments in this domain. This community has taken preliminary steps to address *deep uncertainty*. A significant impediment to improved analysis in the deterrence and assurance domain is the limited number of analysts assigned to the deterrence and assurance mission and the organizational barriers that separate military and nonmilitary analytical agencies addressing deterrence and assurance in a whole-of-government context.[1]

FRAMEWORK FOR ANALYSIS

In broad terms a responsive analysis will include the tasks illustrated in Figure 4-1. Initially, potential adversaries and allies must be identified, together with the deterrence and assurance goals associated with each—those viewed in the larger context of influence, to include combinations of carrots and sticks. Since strategies should be tailored to specific adversary/ally combinations, separate analyses are required for each combination. As displayed in Figure 4-1, the first and most important task in a specific crisis is to understand both adversaries and allies, which can be aided with leadership profiles. These profiles, addressed in Chapter 3 and Appendix E, are designed to identify an adversary's or ally's valued assets, help identify the range of behaviors that might be seen in crisis, assess the barriers to reception of deterrence messages, and estimate responses to perceived messages. They should describe likely changes in these factors as situations change. Given this information, and recognizing that peer/near-peer, regional and nonstate actors pose significantly different challenges, sets of capabilities can be generated and evaluated in terms of effectiveness of actions ("messages") in producing a desired change in adversary behavior. This information can then be used to construct alternative organizations, equipment, and training, assuming different but explicit contributions from other services and government agencies.[2]

Alternatives should be analyzed and evaluated for flexibility, adaptability, and robustness, primarily in the context of uncertainty. Leadership profiles will be subject to varying degrees of uncertainty and error. Accordingly, provision must be made for undesirable, unexpected, and surprising behavior by adversaries and allies. Similarly, alternatives must be examined and evaluated from the perspective of technological surprise and unexpected changes in equipment effectiveness.

[1] Hunter Hustus, Technical Advisor, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, personal communication to the committee on December 19, 2013.

[2] With respect to the Air Force, a broad spectrum of contributions could be brought into play, including, intelligence, surveillance, and reconnaissance and cyber operations. Also, there are second-order contributions such as the use of Air Force assets to deploy missile defense systems.

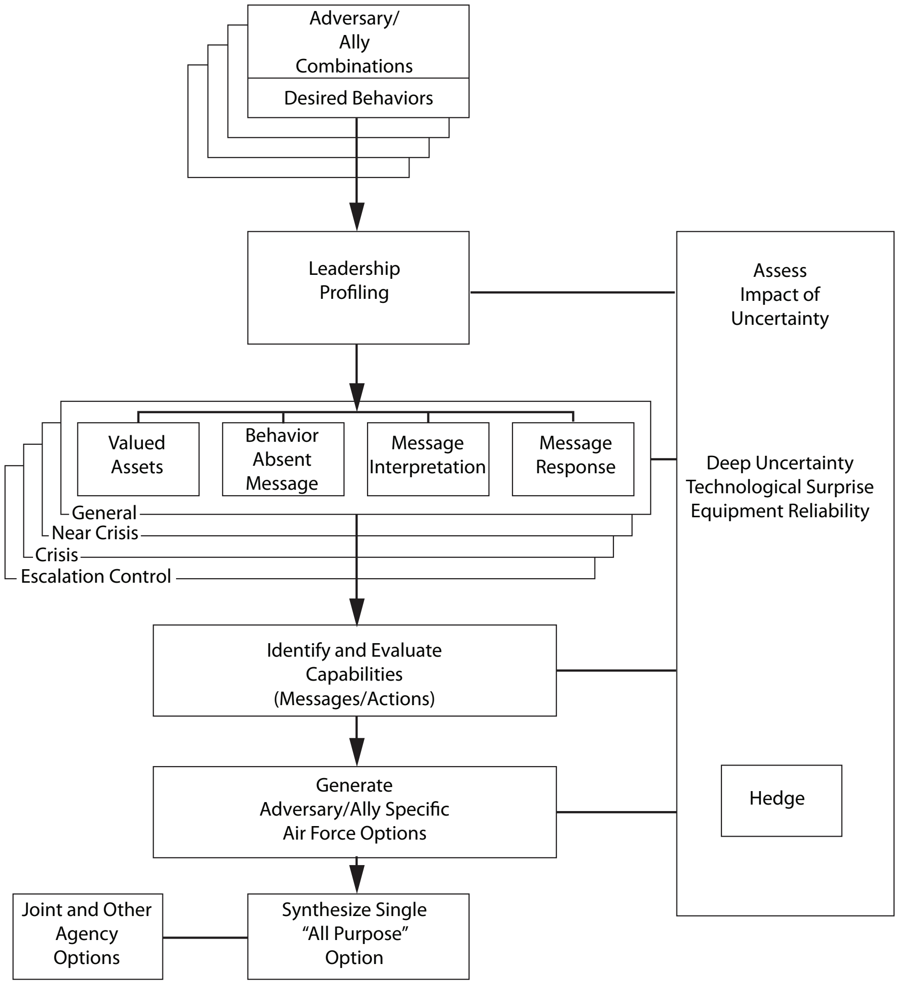

FIGURE 4-1 Notional tasks involved in deterrence analysis.

Sensitivity to the roles of other services, other government agencies, and possible actions by allies should also be analyzed. Keeping in mind the presence of deep uncertainty, assessments must consider the risk of being unable to deliver a particular capability at the time it is needed or the risk that the capability does not produce the desired effect. Such assessments can characterize the alternative under consideration taking into account actor-specific and situation-specific knowledge.

Based on the information developed for the set of adversary/ally combinations, recommended alternatives can be synthesized, integrating the information from the separate analyses to produce one or more options for consideration by the leadership of the Air Force. It is clear that the Air Force is a major but not the only member of the deterrence team. Each of the Services and many other departments and agencies have roles and responsibilities and should be considered in developing understanding and conducting analysis. However, to meet its Title 10 responsibility to organize, train, and equip the Air Force contribution, the Air Force should undertake a series of tasks related to analysis in support of deterrence and assurance.

FINDINGS AND RECOMMENDATIONS

Analysis Plan

Finding 2-2. Analytic Framework. Because the U.S. approach to strategic deterrence and assurance needs to be continually adapted, a management plan is required that defines comprehensively the set of *continuing* analytic foci, which includes nuclear command and control; air and missile defense; cyber, space, geostrategic, and technological changes; and the challenges of tailoring deterrence and assurance to adversaries and allies. This analytic management plan is in addition to tasks related to weapons, forces, personnel, and the nuclear enterprise in general.

Recommendation 1. In support of senior Air Force leadership guidance, including the *Flight Plan for the Air Force Nuclear Enterprise*, the Air Force should develop and maintain a comprehensive strategic deterrence analysis plan to identify the tasks that produce information required to organize, equip, and train Air Force nuclear deterrence and assurance forces and support combatant commanders (Air Force, 2013).

Rationale. Organizing, equipping, and training Air Force elements to be used in conventional and nuclear deterrence and assurance is a critical and complex challenge. The Air Force should develop sound and defensible strategies for developing and fielding its force. Given the current state of scholarship generally and expertise in the Air Force in particular, a multiyear plan for study and analysis of the widening range of deterrence and assurance issues is a key requirement. Furthermore, once in place, an Air Force deterrence and assurance analysis program (DAAP) would provide a means of ensuring that sufficient attention is paid to generating flexible, adaptive, robust strategies, which the committee believes are essential in the nuclear deterrence and assurance domain in the 21st century.

The envisioned DAAP would rely on input from the Department of Defense and other U.S. government agencies. Based on its deliberations, the committee believes that tools, methods, and approaches are available but that an institutionalized means of cross-agency collaboration and coordination does not exist. The analysis plan would provide the basis for establishing such an organization and defining its responsibilities.

Implementation. With respect to implementation, the Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration should be assigned responsibility, with contributions from the Deputy Chief of Staff for Intelligence, Surveillance, and Reconnaissance; the Deputy Chief of Staff for Operations, Plans and Requirements; the Deputy Chief of Staff for Logistics, Installations and Mission Support; the Deputy Chief of Staff for Strategic Plans and Programs; and the Director for Studies and Analyses, Assessments and Lessons Learned, as well as the Air Force Global Strike Command and the Air Force Materiel Command, for developing and recommending to the Chief of Staff of the Air Force an outline of the DAAP.

Actor and Multiactor Modeling

Finding 3-2. Psychological Framework. Deterrence and assurance are largely a psychological concept. Thus, a proper evaluation of proposals for them will rely not only on the balance of military forces but also, whenever possible, on an understanding of the mindset and decision making of the adversary or ally.

Finding 3-3. Tailoring Key Messages. To elicit the intended response, it is important for the sender to have methods and tools that can detect opportunities and send messages tailored to a recipient that is open (willing and able) to make a response based on available information rather than on motivational, affective, or cognitive biases in a deterrence or assurance situation.

Recommendation 2. The Air Force should focus analytic enhancements in support of deterrence and assurance assessment on the human and human organizational factors at the heart of deterrence and assurance.

Rationale. In identifying and assessing analytic "issues and factors that must be considered in seeking nuclear deterrence of adversaries and assurance of allies in the 21st century," the committee noted that deterrence is largely a psychological concept and that sophisticated evaluation of the requisites for deterrence and assurance does not rest solely in the balance of military forces but must include insight into the mindset and decision making of the adversary or ally. An understanding of the impact of any action taken, including unintended consequences, must be central to the design of strategies for deterrence and assurance. Thus, as the number of possible adversaries has grown, so has the need for actor/situation knowledge. The adoption of tailored deterrence results in a set of unique cases that must be considered.

Many analytic methods exist for exploring the nature and content of an individual's or a collective's decision making. These include various content analysis approaches, leadership profiling, qualitative and quantitative cognitive decision modeling, and representing an actor's decision making in agent-based and simulation models. However, it is important to note that because the Air Force is not the only consumer of these analyses it should work to coordinate its needs with the U.S. government agencies that produce information about international leaders in the course of executing their assigned missions. To be skilled users and to generate comprehensive and feasible requirements the Air Force must develop and maintain expertise in this domain. The Air Force will not be solely responsible for production but should make use of Air Force capacity and joint assignments to augment efforts carried out by the primary agencies—that is, the Central Intelligence Agency and Defense Intelligence Agency within the intelligence community and U.S. Strategic Command and other military commands—and ensure that those efforts meet Air Force requirements. Actor and multiactor modeling support both planning and operations. Performed on a continuous basis, this modeling will provide the Air Force with analytic input appropriate to specific deterrence and assurance needs and better estimation of the likelihood of the success of an action based on the decision and risk propensities of adversaries and allies.

Implementation. With respect to implementation, the Air Force Research Laboratory, with input from the Air Force Global Strike Command and the Director for Studies and Analyses, Assessments and Lessons Learned, should be tasked to provide to the Chief of Staff of the Air Force a description of the current state of the Air Force's analytic capabilities in actor and multiactor modeling and a recommended way ahead.

Research

Finding 3-4. Tailored Deterrence. The methods of content analysis and leadership profiling in conjunction with other methods have the potential to help meet requirements of actor-specific knowledge for a strategy of tailored deterrence. An alliance among content analysis, leadership profiling, abstract modeling, and gaming and simulations as a suite of methods is possible in order to solve the complex problems associated with studying the decision-making dynamics of single groups and multiple autonomous actors as decision units.

Recommendation 3. The Air Force, working with its Service partners and the Department of Defense more generally, should pursue research on deterrence and assurance with a coherent approach that involves content analysis, leadership profiling, abstract modeling, and gaming and simulations as a suite of methods. It should organize its investments in analytic and other activities accordingly.

Rationale. While a variety of methods to generate actor- and situation-specific knowledge are available to support Air Force planning for deterrence and assurance, the problem of looking ahead over a planning horizon of 20 years or more places additional demands on the need to understand potential adversaries and allies, being cognizant of the fact that today's adversary may be tomorrow's ally and that regional political–military situations may change, sometimes quickly. One approach to uncertainties such as these is to base analyses on a set of generic decision makers similar to but larger than the four categories described in Chapter 3 in order to explore the degree to which adversaries or allies are willing and able to receive different types of deterrence or assurance messages.

A multimethod approach to this research is necessary and should include many or all of the following methods in addition to others: game theory, human gaming, simulation, qualitative cognitive modeling, agent-based modeling, leadership profiling, and content analysis. An understanding of the variation across decision-making units and contexts will lead to more robust plans by allowing analysts and Air Force leadership to consider a range of motivations, behaviors, consequences, and situations. It would also provide the Air Force with a better appreciation of the implications of leadership changes in state and nonstate adversaries and allies.

Implementation. With respect to implementation, the recommended research deals with an interagency issue. The Office of the Secretary of Defense (OSD) should take the interagency lead, in collaboration with the Joint Chiefs of Staff and U.S. Strategic Command. The Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration should be the focal point for the Air Force and should prepare an Air Force advocacy briefing for approval by the Chief of Staff of the Air Force. The briefing should identify relevant agencies inside and outside the Department of Defense. Once approved, it should then be taken to the Joint Chiefs of Staff, OSD, and the U.S. Strategic Command as a basis for OSD action in an interagency initiative.

Deep Uncertainty

Finding 2-1. Deep Uncertainty. Planning to support deterrence and assurance with both current operations and longer-term programs to organize, equip, and train is characterized by deep uncertainty, described more fully in Chapter 3. Nonetheless, methods exist for dealing with such uncertainties effectively, primarily by hedging and capabilities for adaptation (Hallegate et al., 2012).

Recommendation 4. The Air Force analytic community should pursue methods of understanding and incorporating the concept of deep uncertainty.

Rationale. Among the factors that contribute to deep uncertainty in deterrence and assurance planning are the lack of actor-specific/situation-specific knowledge, limited capacity to predict how messages will be interpreted, random events that may occur during crises or periods of tension, technological surprise, and the impact of fleet-wide capability degradation. Substantial progress has been made on how to plan under deep uncertainty, in which a set of techniques is employed including, for example, alternative cognitive models, test cases, and portfolio management.[3] Use of such techniques is consistent with the analytic approach referred to as hedging, with an emphasis on developing strategies and plans that are flexible, adaptive, and robust.

Implementation. With respect to implementation, the Air Force Research Laboratory, coordinating with the Director for Studies and Analyses, Assessments and Lessons Learned and the Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration, should identify current and anticipated analysis issues in which the concept of deep uncertainty is important and then recommend a program to develop and reinforce relevant knowledge and expertise in the analysis workforce.

Methods

Finding 3-4. Tailored Deterrence. The methods of content analysis and leadership profiling, in conjunction with other methods, have the potential to help meet requirements of actor-specific knowledge for a strategy of tailored deterrence. An alliance among content analysis, leadership profiling, abstract modeling, and gaming and simulations as a suite of methods is possible in order to solve the complex problems associated with studying the decision-making dynamics of single groups and multiple autonomous actors as decision units.

Recommendation 5. Air Force analysis supporting nuclear deterrence and assurance issues should draw from a suite of appropriate methods, including hybrid methods that combine and integrate different methods.

Rationale. In examining the need to solve and understand the decision-related dynamics of effective deterrence and assurance, the committee recognized the potential value of conducting analyses on the basis of a combined approach. Indi-

[3] Davis (2012) is a broad review of RAND's work on dealing with uncertainty. For further discussion of methods to support "robust decision making," see Lempert et al. (2006).

vidual methods that might be included are content analysis, leadership profiling, abstract modeling, and gaming simulation. In many respects this is consistent with current and past practices for conducting deterrence analyses in which a wide range of methods have been used.

The notion of tailoring deterrence poses a set of analytic challenges in which certain attributes and factors will differ, perhaps significantly, across the range of adversaries, allies and regions. The committee believes that methods must be selected, adapted when necessary, and applied by analysts with two types of expertise: (1) sufficient facility with a variety of analytic methods to be able to distinguish appropriate use of each and (2) knowledge of the deterrence and assurance actors and processes relevant to the analysis task.

Hybrid methods involving the integration of expertise drawn from multiple disciplines, and the application of the analytic approaches of those disciplines in an integrated and novel way, were evident in the committee's investigation and assessment of theory, applications, and research addressing decision-making units. In this domain and across the extent of nuclear deterrence and assurance analysis, hybrid methods offer greater breadth and accuracy because of the multiple disciplines involved. They may contribute to developing a wider range of insights.

Implementation. With respect to implementation, Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration should coordinate with the Director for Studies and Analyses, Assessments and Lessons Learned to describe the unique attributes of deterrence and assurance analysis and the value of integrated hybrid approaches. Based on that description, the Director for Studies and Analyses, Assessments and Lessons Learned and the Air Force Education and Training Command should recommend a program to ensure that analysts have the knowledge and expertise required to bring appropriate hybrid approaches to bear on the analyses of deterrence and assurance issues.

Analysts

Finding 3-1. Long-Term Career Development. Education and nurturing of experts in deterrence and assurance will not happen without a management plan to do so in the Air Force (and other services, particularly the Navy), partly in coordination with joint assignments but also bearing in mind longer-term career development and assuring adequate expertise (a Service responsibility).

Recommendations 6. The Air Force should maintain its cadre of career analytic professionals (both civilian and military) with expertise in nuclear deterrence and assurance strategy to improve Air Force support to Combatant Commanders' planning and operations, since methods can inform, but never replace, the judgment of expert analysts. This could be facilitated by specific treatment of analysts in Vector 5 of the *Flight Plan for the Air Force Nuclear Enterprise* (Air Force, 2013).

Rationale. In the course of its efforts the committee was briefed on current analyses related to deterrence and assurance and on various methods. These briefings led to a critical finding—namely, that the primary element in improving and sustaining high-quality analysis of deterrence and assurance is the continued education and nurturing of people, which should include frameworks, theory, and critical reasoning. The nation currently has a small pool of such analysts, who are very capable, but the pool is not large enough.

While the qualifications required of an analyst in the deterrence and assurance domain include a thorough understanding of the methods widely used throughout the military analysis enterprise, deterrence and assurance have attributes that require specialized expertise. Unfortunately the number of deterrence and assurance "experts" appears to be declining as personnel with experience dating back to the Cold War retire. It is possible for people to gain and retain knowledge necessary to conduct sophisticated deterrence and assurance analysis and planning without becoming career specialists. Such knowledge can be acquired through academic courses and experiential learning tailored to the 21st century security environment, yet deterrence and assurance analysis is currently underresourced. If the Air Force is to develop analytically based strategies and perspectives that are credible in the joint arena, and if Air Force leaders are to be prepared with reliable, informed reviews of alternative options considered in that arena, then the relevant analytic community must be adequately resourced.

Implementation. With respect to implementation, the Air Force Education and Training Command should be tasked, in coordination with Deputy Chief of Staff for Intelligence, Surveillance, and Reconnaissance; the Director for Studies and Analyses, Assessments and Lessons Learned; and the Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration to provide a way-ahead briefing for the Chief of Staff of the Air Force.

THE VALUE PROPOSITION FOR IMPLEMENTING THE RECOMMENDATIONS

In the process of preparing for this report the committee was given the opportunity to interact with analysts currently engaged in planning for deterrence and assurance and in supporting deterrence and assurance missions. Given the resources available, these people are doing a remarkable job. The current community makes excellent use of classical analytic methods. It has begun to address the challenge of actor-specific and situation-specific knowledge but is not resourced to exploit advances in these disciplines. It has taken only preliminary steps to address deep uncertainty and has limited capacity for the research necessary to develop new deterrence and assurance concepts, theories, and strategies.

The report's recommendations respond to observed shortfalls and identified opportunities. The development of an comprehensive analysis plan will provide a framework in which to develop strategies for organizing, equipping, and training Air Force personnel. It will allow the Air Force to avoid overreliance on tools that are most appropriate for physics or engineering questions and contribute to the adoption of well-hedged, robust, and adaptive strategies. Increasing the Air Force analytic capacity to understand and utilize human and human organization factors will inform the region by region contributions the Air Force must make to tailored deterrence, facilitate earlier recognition of potential failure, expand understanding of the risk-taking behavior of adversaries and allies as well as allowing more specific tailoring of the Air Force response to potential deterrence or assurance needs. Advocacy of research to develop a generalized understanding of leadership, decision making, and behavior dynamics related to deterrence and assurance will improve the robustness of longer-term planning, provide a region by region baseline deterrence environment and assist in responding to leadership changes in adversaries or allies. Incorporating deep uncertainty into Air Force analyses supporting strategic planning will reduce the risk of being unprepared for unforeseen situations, increase awareness of the value of hedging in the face of uncertainty, and provide an approach to identifying and dealing with unintended consequences. All of these recommendations rely on the cadre of Air Force career analytic professionals. These professionals ensure that the Air Force has credible and analytically based perspectives in the joint arena, and that Air Force leadership is provided with informed and reliable information to support selection of an Air Force strategy, plans, and materiel.

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Appendixes

A

Terms of Reference

Mindful of the different classes of adversaries in the 21st Century and recent U.S. policy statements regarding the Triad and the strategy for employing U.S. nuclear forces, an ad hoc committee will:

1. Identify the broad analytic issues and factors that must be considered in seeking nuclear deterrence of adversaries and assurance of allies in the 21st Century.
2. Describe and assess tools, methods—including behavioral science-based methods—and approaches for improving the understanding of how nuclear deterrence and assurance work or may fail in the 21st Century and the extent to which such failures might be averted or mitigated by the proper choice of nuclear systems, technological capabilities, postures, and concepts of operation of American nuclear forces.[1]
3. Discuss the implications for the Air Force and how it could best respond to these deterrence and assurance needs. Include in this discussion a framework for identifying the risks and benefits associated with different nuclear force postures, structures, levels, and concepts of operation.

[1] The committee interpreted this to mean that it should describe and assess methods and tools that would help both (1) in improving and understanding deterrence and (2) in helping to understand how nuclear forces, posture, technological capabilities, and concepts of operations can improve prospects or mitigate failures. The committee and the Air Force sponsor understood that the study was not going to make recommendations about force structure and the like.

4. Recommend criteria and a framework for validating the tools, methods, and approaches; and for identifying those most promising for Air Force usage.

5. Recommend an appropriate mix of the classes of analytical tools affordable in today's austere financial climate, and identify what can be planned for by the Air Force as future improvements to this mix if and should defense budgets increase or decrease.

B

Biographical Sketches of Committee Members

GERALD F. PERRYMAN, JR., *Co-Chair*, is an independent consultant. Upon concluding military service with the U.S. Air Force in 2002 as a major general, Gen Perryman joined Raytheon Company as vice president and lead executive for the company's intelligence, surveillance, and reconnaissance (ISR) Strategic Business Area. There he developed strategies for ISR growth using capabilities from across that diverse, global company, helping it provide integrated mission systems. Prior to his Raytheon work, Gen Perryman was assistant deputy chief of staff, Warfighting Integration, Headquarters U.S. Air Force, providing guidance and direction for transforming Air Force warfighting capability by integrating command and control, communications and computer networks, and ISR systems. Earlier Gen Perryman had led the Air Force's Aerospace Command and Control and ISR Center at Langley Air Force Base. He had commanded the 14th Air Force, which encompasses all Air Force space operations forces worldwide. He had also commanded both an Air Force space wing and a strategic missile wing. He currently serves on the National Research Council's (NRC's) Air Force Studies Board and is a past member of the Committee on Examination of the Air Force ISR Capability Planning and Analysis Process. A graduate of Texas A&M University, Gen Perryman received his MBA from the University of North Dakota.

ALLISON ASTORINO-COURTOIS, *Co-Chair*, is executive vice president at National Security Innovations (NSI), Inc. She has served as technical lead on a number of Office of the Secretary of Defense (OSD) multi-layer analysis (SMA) projects in support of U.S. forces and combatant commands. Prior to joining NSI, Dr. Astorino-Courtois worked for Science Applications International Corporation (2004-2007), where she served as a U.S. Strategic Command liaison to U.S. and international communities and was a tenured associate professor of international relations at Texas A&M University in College Station (1994-2003), where her research focused on the cognitive aspects of foreign policy decision making. She has received a number of academic grants and awards and has published articles in multiple peer-reviewed journals including *International Studies Quarterly, Journal of Conflict Resolution*, *Political Psychology*, *Journal of Politics,* and *Conflict Management and Peace Science.* She has also taught at Creighton University and was a visiting instructor at the U.S. Military Academy at West Point. Dr. Astorino-Courtois earned her Ph.D. in international relations from New York University.

JOHN F. AHEARNE is executive director emeritus of Sigma Xi, the Scientific Research Society; emeritus director of the Sigma Xi Ethics Program; and an adjunct professor of engineering at Duke University. Prior to working at Sigma Xi, Dr. Ahearne served as vice president and senior fellow at Resources for the Future and as commissioner and chair of the U.S. Nuclear Regulatory Commission. He worked in the White House Energy Office and as Deputy Assistant Secretary of Energy at the U.S. Department of Energy. He also worked on weapons systems analysis, force structure, and personnel policy as deputy and principal deputy assistant secretary of defense. Serving in the U.S. Air Force, he worked on nuclear weapons effects and taught at the Air Force Academy. Dr. Ahearne's research interests include risk analysis, risk communication, energy analysis, reactor safety, radioactive waste, nuclear weapons, materials disposition, science policy, and environmental management. He was elected to the National Academy of Engineering (NAE) in 1996 for his leadership in energy policy and the safety and regulation of nuclear power. Dr. Ahearne has served on and chaired numerous NRC committees related to U.S. strategic deterrence, including the Committee on Russian Academy of Sciences/U.S. National Academies Joint Committee on U.S.-Russian Cooperation on Nuclear Non-Proliferation; the Committee on Counterterrorism Challenges for Russia and the United States; and the Committee on Opportunities for U.S.-Russian Collaboration in Combating Radiological Terrorism. Dr. Ahearne earned his Ph.D. in physics from Princeton University.

GERALD G. BROWN is a Distinguished Professor of Operations Research and executive director of the Center for Infrastructure Defense at the Naval Postgraduate School, where he has taught and conducted research in optimization and optimization-based decision support since 1973, earning awards for both outstanding teaching and research. His military research has been applied by every uniformed service, in areas ranging from strategic nuclear targeting to capital planning. He has been awarded the Barchi, Rist, and Thomas prizes for military operations research and been credited with guiding investments of more than a trillion dollars. He has designed and implemented decision support software used by the majority of the Fortune 50 Companies, in areas ranging from vehicle routing to supply chain optimization. His research appears in scores of open-literature publications and classified reports, some of which are seminal references. Dr. Brown is a member of the NAE, a recipient of the U.S. Navy Distinguished Civilian Service Medal, an INFORMS fellow, and a founding director of Insight, Incorporated, the leading provider of strategic supply chain optimization tools to the private sector. He currently serves on NRC boards on Mathematics, Statistics and their Applications, and on Explosives and Survivability.

ALBERT CARNESALE is chancellor emeritus and professor at the University of California, Los Angeles (UCLA). He was chancellor of the university from 1997 through 2006 and now serves as professor of public policy and of mechanical and aerospace engineering. Prior to joining UCLA, he was at Harvard University for 23 years as the Lucius N. Littauer Professor of Public Policy and Administration, dean of the John F. Kennedy School of Government, and provost of the University. Prior to that, he served in both government and industry. His research and teaching focus on public policy issues having substantial scientific and technological dimensions, and he is the author or co-author of six books and more than 100 articles on a wide range of subjects, including national security strategy, arms control, nuclear proliferation, the effects of technological change on foreign and defense policy, domestic and international energy issues, and higher education. He is a member of the NAE and of the Council on Foreign Relations; is a fellow of the American Academy of Arts and Sciences and of the American Association for the Advancement of Science; and serves on the board of directors of Harvard University's Belfer Center for Science and International Affairs and on the advisory board of the RAND Corporation's Center for Global Risk and Security. He was a member of the Obama administration's Blue Ribbon Commission on America's Nuclear Future. He chaired the NRC Committees on NASA's Strategic Direction, on America's Climate Choices, on Sustaining and Improving the Nation's Nuclear Forensics, and on U.S. Conventional Prompt Global Strike Capabilities. Dr. Carnesale holds a Ph.D. in nuclear engineering from North Carolina State University.

W. PETER CHERRY is an independent consultant who retired in 2010 as the chief analyst on the U.S. Army's Future Combat Systems Program at Science Applications International Corporation (SAIC). He was responsible for analytic support to requirements analysis, performance assessment, and design trades. Previously, Dr. Cherry was leader of the Integrated Simulation and Test Integrated Program Team, focusing on test and evaluation planning, the development of associated models and simulations, and the development of the Future Combat System of

Systems Integration Laboratory. He was a participant in the Future Combat Systems program from its inception, leading analysis and evaluation of concepts as a member of the Full Spectrum Team during the contract activities that preceded concept and technology development. Since the completion of his studies at the University of Michigan, he has focused on the development and application of operations research in the national security domain, primarily in the field of land combat. He contributed to the development and fielding of many of the major systems employed by the Army, ranging from the Patriot Missile System to the Apache helicopter, as well as command control and intelligence systems such as ASAS and AFATDS. In addition, he contributed to the creation of the Army's Manpower Personnel and Training Program (MANPRINT) and to the Army's Embedded Training Initiative. His recent research interests include peacekeeping operations and the development of transformational organizations and materiel. Dr. Cherry was a member of the Army Science Board and served as chair of the Board's Logistics Subpanel. In addition he has participated over the past 10 years in independent reviews of the Army's science and technology programs and on NRC studies addressing a variety of defense issues. Dr. Cherry received a Ph.D. in industrial engineering from the University of Michigan. He is currently a member of the Board on Army Science and Technology, a fellow of INFORMS, and a member of the NAE.

PAUL K. DAVIS is a senior principal researcher at the RAND Corporation and a professor of policy analysis in the Pardee RAND Graduate School. His research interests include strategic planning and methods for improving it, decision-making theory, counterterrorism, and advanced methods of analysis and modeling (notably exploratory analysis and multiresolution modeling). He has authored or coauthored widely read books on defense planning, capabilities-based planning, portfolio analysis, and deterrence and influence theory, as well as an integrative review on social science for counterterrorism. Before joining RAND, Dr. Davis was a senior executive at the Department of Defense (DoD). He has served on numerous national panels for DoD, the National Academies, and the intelligence community. He also is a regular reviewer on several professional journals. Dr. Davis served as a member of the NRC Committee on Conventional Prompt Global Strike Capability and the Committee on Modeling and Simulation for Defense Transformation. He received his Ph.D. in chemical physics from the Massachusetts Institute of Technology.

STEPHEN DOWNES-MARTIN is currently a research professor at the U.S. Naval War College and has over 30 years of experience in developing and applying war gaming, game theory, decision analysis, and systems thinking to tactical, operational, and strategic military problems for a wide variety of government, military, aerospace, and commercial organizations in the United States and abroad. His research focus is on how decision support and assessment methods can be manipulated to deceive decision makers, how decision makers misuse such methods to deceive themselves, how to detect such attempts and protect from them. In 2010, he was awarded the Superior Civilian Service medal for in-theater support of I Marine Expeditionary Force (Forward) and Regional Command (Southwest) in Afghanistan. During Spring 2012, he supported in-theater the Afghan Assessment Group at ISAF HQ, Kabul. He was a reserve military intelligence officer in the British Army, and is now a U.S. citizen. Dr. Downes-Martin holds a Ph.D. in mathematical physics from London University.

KATHLEEN L. KIERNAN is the founder and chief executive officer of Kiernan Group Holdings, Inc. Dr. Kiernan is a 29-year veteran of Federal Law Enforcement. She previously served as the assistant director in the Office of Strategic Intelligence and Information for the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF), where she was responsible for the design and implementation of an intelligence-led organizational strategy to mine and disseminate data related to explosives, firearms, and illegal tobacco diversion, the traditional and nontraditional tools of terrorism. Dr. Kiernan is the chair emeritus for the InfraGard Program, a public–private alliance with over 62,000 members representing all 18 critical infrastructures and key resources. She co-chairs the Homeland Security Intelligence Council (HSIC) for the Intelligence and National Security Alliance and is the former chair of the Division of Criminal Investigation's Law Enforcement Working Group, an initiative designed to bridge the communities of intelligence and law enforcement. Dr. Kiernan is a senior member on the International Association of Chiefs of Police Terrorism subcommittee and serves on the Board of Regents of the Potomac Institute for Policy Studies. Dr. Kiernan served as the ATF representative to the Counterterrorism Center at the CIA during 1993 and 1995; is the Council vice president for ASIS International, with oversight of the Critical Infrastructure Working Group; and chairs the Domestic Intelligence Council for the Intelligence and National Security Alliance. Dr. Kiernan led a nationwide intelligence community project involving the active interdiction of weapons of mass destruction throughout the law enforcement and public safety communities and led a team in the Quadrennial Intelligence Community Review. Dr. Kiernan serves as a subject matter expert for the Rapid Reaction Technology Office in the OSD and other elements of the defense community. Dr. Kiernan was the recipient of the Women of Influence—Public Sector award in 2010. Dr. Kiernan completed her doctorate in education at Northern Illinois University and her master of science in strategic intelligence at the Joint Military Intelligence College in Washington, D.C. She also holds a master of arts in international transactions from George Mason University Homeland Security Policy Institute and is a faculty member at Johns

Hopkins University and the Naval Postgraduate School's Center for Homeland Defense and Security.

RONALD F. LEHMAN II is the Counselor at Lawrence Livermore National Laboratory (LLNL). Dr. Lehman is also chairman of the governing board of the International Science and Technology Center and vice chair of DoD's Threat Reduction Advisory Committee. He recently co-chaired the study on the future of cooperative threat reduction For 16 years, he headed the Center for Global Security Research at LLNL. Dr. Lehman was director of the U.S. Arms Control and Disarmament Agency from 1989 to 1993, when START I, START II, the Chemical Weapons Convention, and other historic agreements were concluded. Previously, he served in DoD as Assistant Secretary for International Security Policy, in the State Department as Ambassador and U.S. Chief Negotiator on Strategic Offensive Arms (START I), and in the White House as Deputy Assistant to the President for National Security Affairs. He has also served on the National Security Council staff as a senior director, in the Pentagon as deputy assistant secretary, on the senior professional staff of the U.S. Senate Armed Services Committee, and in Vietnam commissioned in the U.S. Army. In past years, he served on the Presidential Advisory Board on Proliferation Policy, on the State Department's International Security Advisory Board, as chair of the NATO High Level Group, on the governing board of the U.S. Institute of Peace, and as a U.S. representative to a number of United Nations disarmament and review conferences.

JOHN A. MONTGOMERY is the director of research at the Naval Research Laboratory (NRL), where he oversees research and development programs with expenditures of approximately $1.2 billion per year. He joined the NRL in 1968 as a research physicist in the Advanced Techniques Branch of the Electronic Warfare Division, where he conducted research on a wide range of electronic warfare (EW) topics. In 1980, he was selected to head the Off-Board Countermeasures Branch. In May 1985, he was appointed to the Senior Executive Service (SES) and was selected as superintendent of the Tactical EW Division. He has been responsible for numerous systems that have been developed/approved for operational use by the Navy and other services. He has had great impact through the application of advanced technologies to solve unusual or severe operational deficiencies noted during world crises, most recently in Afghanistan, Iraq, and for Homeland Defense and in the Pacific theater. Dr. Montgomery received the DoD Distinguished Civilian Service Award in 2001. He was recognized by the Department of the Navy Distinguished Civilian Service Award in 1999 and by the Department of the Navy Meritorious Civilian Service Award in 1986. As a member of the SES, he received the Presidential Rank Award of Distinguished Executive in 1991 and again in 2002, and the Presidential Rank Award of Meritorious Executive in 1988, 1999, and again in 2007. He also received the 1997 Dr. Arthur E. Bisson Prize for Naval Technology Achievement, awarded by the Chief of Naval Research in 1998. Further, he has received the Association of Old Crows (Electronic Defense Association) Joint Services Award in 1993. He was an NRL Edison Scholar, and is a member of the NAE and of Sigma Xi. He served as the U.S. national leader of the Technical Cooperation Program's multinational Group on EW from 1987 to 2002, and served as its executive chairman. In 2006, Dr. Montgomery received the Laboratory Director of the Year award from the Federal Laboratory Consortium for Technology Transfer, and in 2011 he received the Roger W. Jones Award for Executive Leadership from American University's School of Public Affairs. Dr. Montgomery received his Ph.D. in physics from the Catholic University of America.

JERROLD M. POST is professor of psychiatry, political psychology, and international affairs and director of the Political Psychology Program at George Washington University. Dr. Post has devoted his entire career to the field of political psychology. Dr. Post came to George Washington after a 21-year career with the Central Intelligence Agency, where he was the founding director of the Center for the Analysis of Personality and Political Behavior. He played the lead role in developing the "Camp David profiles" of Menachem Begin and Anwar Sadat for President Jimmy Carter and initiated the U.S. government program in understanding the psychology of terrorism. In recognition of his leadership at the center, Dr. Post was awarded the Intelligence Medal of Merit in 1979. He received the Nevitt Sanford Award of the International Society of Political Psychology in 2002 for Distinguished Professional Contributions to Political Psychology. In December 1990, he testified before the House Armed Services Committee and the House Foreign Affairs Committee on the political personality profile of Saddam Hussein he had developed. Since 9/11, he has testified on the psychology of terrorism before the Senate, the House, and the United Nations. Dr. Post has written or edited 10 books, including *The Psychological Assessment of Political Leaders*, *Leaders and Their Followers in a Dangerous World*, and *The Mind of the Terrorist*, and he contributed the lead chapter "Actor-Specific Behavioral Models of Adversaries: A Key Requirement for Tailored Deterrence" in *Tailored Deterrence: Influencing States and Groups of Concern*. He is a frequent commentator in national and international media on such topics as the psychology of leadership, the psychology of terrorism, weapons of mass destruction, Osama bin Laden, Hugo Chavez, Mahmoud Ahmadinejad, Kim Jong Il, Muammar Qaddafi, and, most recently, Bashar al-Assad. Dr. Post received his baccalaureate degree magna cum laude from Yale College. After receiving his medical degree from Yale, where he was elected to Alpha Omega Alpha, the honor medical society, he received postgraduate training in psychiatry at Harvard Medical School and the National Institute of Mental Health.

BARRY R. SCHNEIDER is a professor of international relations at the Air War College and the retired director of the U.S. Air Force Counterproliferation Center at Maxwell Air Force Base. Dr. Schneider specializes in weapons of mass destruction counterproliferation and nonproliferation issues as well as the profiles of adversary leaders and their strategic cultures. He is the author of *Future War and Counterproliferation: U.S. Military Responses to NBC Proliferation Threats* (1999); the editor, of *Middle East Security Issues, In the Shadow of Weapons of Mass Destruction Proliferation* (1999), and contributor to and coeditor of *Avoiding the Abyss: Progress, Shortfalls and the Way Ahead in Combating WMD* (2005, 2006)*; Know Thy Enemy: Profiles of Adversary Leaders and Their Strategic Cultures* (2003), *The Gathering Biological Warfare Storm* (2002), *Pulling Back from the Nuclear Brink: Reducing and Countering Nuclear Threats* (1998), *Battlefield of the Future: 21st Century Warfare Issues* (1998), *Missiles for the Nineties: ICBMs and Strategic Policy* (1984), and *Current Issues in U.S. Defense Policy* (1976). He has served as a foreign affairs officer (GS-14) and public affairs officer (GS-15) at the U.S. Arms Control and Disarmament Agency, as a congressional staffer on arms control and defense issues, and was a senior defense analyst at the Harris Group and the National Institute for Public Policy. He has taught at the Air War College since 1993. As a faculty member, he has taught core courses of instruction and elective courses in areas such as international rivals, homeland security issues, international flashpoints, counterproliferation issues, 21st century warfare issues, and CBW issues for the Air Force. He has taught at five other colleges and universities and has a Ph.D. in political science from Columbia University.

STEPHEN G. WALKER is emeritus professor of political science in the School of Politics and Global Studies at Arizona State University. He has published *Role Theory and Foreign Policy Analysis* (1987), *Beliefs and Leadership in World Politics* (2006), *Rethinking Foreign Policy Analysis* (2011), and *U.S. Presidents and Foreign Policy Mistakes* (2011), plus articles in several journals, including *World Politics, Journal of Conflict Resolution, Journal of Peace Research, International Studies Quarterly, International Interactions, Foreign Policy Analysis,* and *Political Psychology.* The National Science Foundation funded his research on the belief systems and conflict management strategies of political leaders (1982-1983). He served as a coeditor of *International Studies Quarterly* (1985) and as a vice-president of the International Society of Political Psychology (1997-1999) and the International Studies Association (2003-2004). He received the Distinguished Scholar Award from the Foreign Policy Section of the International Studies Association in 2003.

MICHAEL O. WHEELER is a member of the senior research staff at the Institute for Defense Analyses (IDA) and since 1991, a past member of the Strategic Advisory Group at USSTRATCOM. A 1966 graduate of the U.S. Air Force Academy, Dr. Wheeler retired in 1991 at the rank of Colonel. While in the Air Force, he served in tactical and strategic air commands, in Thailand during the Vietnam War, on the Air Staff, at the National Security Council and the State Department, on the faculty of the U.S. Air Force Academy, and on the Joint Staff. At retirement, he was the arms control advisor to the chairman of the Joint Chiefs of Staff. In 1978 and 1979, Dr. Wheeler was a White House fellow. Following retirement from the Air Force, Dr. Wheeler joined strategic studies centers, first at System Planning Corporation, then at SAIC, and then at IDA. Dr. Wheeler also has served on Defense Science Board task forces and on the advisory committees for Lawrence Livermore National Laboratory and the National Nuclear Security Administration. He was the executive secretary of the congressionally chartered Commission on Nuclear Expertise (aka the Chiles Commission), and from 2006 to 2008, was director of the Advanced Systems and Concepts Office at the Defense Threat Reduction Agency. He has published broadly in national security affairs. Dr. Wheeler holds a Ph.D. in philosophy from the University of Arizona.

C

Meetings and Speakers

MEETING 1
JUNE 26-27, 2013
KECK CENTER OF THE NATIONAL ACADEMIES
WASHINGTON, D.C.

Vision for the Study
Michael Shoults, Senior Executive Service, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, Headquarters U.S. Air Force

Air Force Global Strike Command Perspectives
Duane Hiebsch, Chief, Strategic Plans (A8X)

Regional Conflict and Nuclear Deterrence
David Stein, Office of the Secretary of Defense (Policy)

Defense Intelligence Agency (DIA) Perspectives
Pamela McCue, Deputy Director for Analytic Resources, DIA

Discrimination and Escalation Management in U.S. Nuclear Policy
Elbridge Colby, Principal Analyst and Division Lead for Global Strategic Affairs, Strategic Initiatives Group, Center for Naval Analyses

Joint Staff Perspectives
Timothy G. Fay, Deputy Director, Command, Control and Nuclear Operations, Joint Staff

Recent Deterrence Studies at IDA
Mike Wheeler, Senior Research Staff Member, Institute for Defense Analyses

RAND Corporation (Results of Recent Studies)
Paul Davis, Principal Researcher, Pardee Graduate School

MEETING 2
SEPTEMBER 17-19, 2013
U.S. STRATEGIC COMMAND
OFFUTT AIR FORCE BASE, NEBRASKA

Deterrence Planning
STRATCOM J52, J53, J55

Wargaming
STRATCOM J55

Force Structure Analysis
STRATCOM J55 and J87

Stockpile Sizing
STRATCOM J87

Campaign Plan Assessment
STRATCOM J9

Ongoing Areas of Improvement
JFCC GS, STRATCOM J55

MEETING 3
OCTOBER 8-9, 2013
KECK CENTER OF THE NATIONAL ACADEMIES
WASHINGTON, D.C.

North Korea's WMD Profile
Katy Hassig, Senior Research Staff Member, Institute for Defense Analyses

Iran
Gregory Giles, SAIC

Deterrence of Russia: Past and Present
Linton F. Brooks, Department of Energy (retired)

China
J. Stapleton Roy, Distinguished Scholar and Founding Director Emeritus, Kissinger Institute on China and the United States Wilson Center

Deterrence and the Social Sciences
Hriar Cabayan, Joint Staff/J-38

Narrative Dimensions of Deterrence: Recent Developments in Neurobiology
William Casebeer, Program Manager, DARPA

MEETING 4
NOVEMBER 19-21, 2013
ARNOLD AND MABEL BECKMAN CENTER
UNIVERSITY OF CALIFORNIA AT IRVINE

Crisis Stability and Long-Range Strike
Forrest Morgan, Senior Political Scientist, RAND Corporation

Reducing the Great Divide: Leveraging the Data Deluge to Modernize Operational Deterrence Analytics
Andrea Little Limbago, Chief Social Scientist, Berico Technologies

Ballistic Missile Defense and Associated Analytic Issues
John Ahearne, Executive Director Emeritus, Sigma Xi, The Scientific Research Society

An Enabler for Smart Power Analytics: The Hybridization of Algorithmic and Heuristical Methodologies and Tools—The Vit Tall Analytical Approach
Steve Chan, Director/Senior Fellow, IBM Network Science Research Center/ Harvard Kennedy School Center for Public Leadership

WMD and Deterrence: A Game-Theoretic Overview
Robert Powell, Robson Professor of Political Science, University of California, Berkeley

Quantitative Approaches to the Study of Nuclear Deterrence
Matthew Fuhrmann, Assistant Professor of Political Science, Texas A&M University

Deterrence in Context
Patrick Morgan, Emeritus Tierney Chair, Peace and Conflict, Political Science School of Social Sciences, University of California, Irvine

Sanctions, Statecraft, and Nuclear Proliferation
Etel Solingen, Thomas T. and Elizabeth C. Tierney Chair in Peace Studies, Political Science School of Social Sciences, University of California, Irvine

Perspectives
Brad Roberts, William J. Perry Fellow in International Security, Stanford University

WRITING MEETINGS

- Meeting 5, December 17-19, 2013, AT&T Conference Center, University of Texas, Austin
- Meeting 6, January 13-15, 2014, The Keck Center of the National Academies, Washington, D.C.

D

Tailored Deterrence and Strategic Capabilities: Situation-Specific Knowledge of Peers, Near-Peers, Regional, and Non-State Actors

INTRODUCTION

The changing international security environment since the end of the Cold War between the United States and the Soviet Union has created incentives to revisit with new approaches, methods, and tools the Cold War doctrine of strategic deterrence as the cornerstone of U.S. national security strategy. The principal change that has prompted a reassessment is the transformation of the international system from a bipolar world in which the Soviet Union posed the only major threat of an armed attack on the United States with nuclear weapons to a world of multiple potential adversaries with different cultures and decision-making processes and armed with nuclear weapons or other weapons of mass destruction (WMD).

Does this more complex strategic environment demand a more complex strategy of nuclear deterrence for the Air Force, the Department of Defense (DoD) and the other elements of the U.S. national security community (Morgan, 2003)? A comprehensive answer to this question appeared in a review of U.S. deterrence strategy by DoD in 2006, summarized as follows by Bunn (2007, p. 1):

> In its 2006 *Quadrennial Defense Review (QDR) Report*, the Bush administration set forth a vision for tailored deterrence, continuing a shift from a one-size-fits-all notion of deterrence toward more adaptable approaches suitable for advanced military competitors, regional

> weapons of mass destruction (WMD) states, as well as non-state terrorist networks, while assuring allies and dissuading potential competitors.[1]

Bunn (p. 1) pointed out that this official U.S. document was the one in which the term tailored deterrence first appeared but without explaining what it means in detail or how this strategy might be carried out. However, 7 years later it is the term of art to describe the joint strategy of deterrence pursued by the United States and South Korea in dealing with the threat posed by North Korea (Parish, 2013) and has become the focus of increased attention in the academy and by analysts in the policy community (Post, 2012; Schneider and Ellis, 2012; Lowther, 2013a).

Bunn (2007) identified three aspects of any deterrence strategy and specifically highlighted a fourth aspect in a tailored deterrence strategy. Any deterrence strategy has a focus on (1) the *adversary's action* to be deterred, (2) the *agent's military capabilities* necessary to deter the action, and (3) the *communications capabilities* necessary to provide the adversary with information about the action to be deterred and the agent's military capabilities. A tailored deterrence strategy highlights specifically the *situation-specific knowledge* and *actor-specific knowledge* required to communicate this information to the adversary and thereby deter the action.

In Bunn's words (p. 1), "Deterrence aims to prevent a hostile action (for example, aggression or WMD use) by ensuring that, in the mind of a potential adversary, the risks of action outweigh the benefits, while taking into account the consequences of inaction." This statement is not the whole story, since adversaries do not always do a rational cost-benefit calculation and act accordingly. Further, success in deterrence often depends on a broader set of influences, such as the organizational and societal characteristics of the deteree, as described below.

To take account of these complexities, a tailored deterrence strategy in the current strategic environment requires actor-specific knowledge about a variety of actual and potential adversaries whose culture and cost/benefit calculus may differ, depending on the type of decision unit (predominant leader, single group, or a coalition of multiple autonomous actors) that defines the governmental decision units of different adversaries and the cultures of the societies in which these governments are located (Allison, 1969; Hermann and Hermann, 1989; Post, 2012).

Tailoring deterrence and assurance strategies calls as well for situation-specific knowledge. The external position of the adversary or ally in the regional or global strategic environment needs to be taken into account to implement a tailored strategy of deterrence or assurance. Are the adversaries and allies peers and near-peers, regional actors, or non-state actors? Do they have weapons of mass destruction and the means to use them (Bunn, 2007; Schneider and Ellis, 2012)? Is the occasion

[1] Bunn's summary is taken from Department of Defense (2006, p 2). She notes additional discussion of tailored deterrence in this document is on pages 4, 27, and 50-51.

for making decisions a general deterrence or assurance situation; an immediate deterrence or assurance situation; or an extended deterrence or assurance situation (Morgan, 1983, 2003)? Also, is it a crisis or noncrisis situation in which the task is to establish credibility and dissuade adversaries or allies from escalating a conflict (Hermann, 1969; Brecher and Wilkenfeld, 2000)? Is it a potential proliferation situation in which the arms control task is to strengthen trust and dissuade allies or adversaries from taking independent action to acquire or increase their nuclear capabilities (Morgan, 2003; Bunn, 2007)?

In summary, tailoring a strategy must account for myriad details, ranging from the objective and emotional stakes of affected parties, internal domestic politics in all of the parties involved, to the operational military capabilities of all parties. What follows draws on political science research in the area of comparative foreign policy analysis to highlight and integrate these considerations that operate at different levels of analysis. The goal is to provide a clear and concise analytical framework for identifying how adversaries and allies see and think about the strategic environment, in order to reduce uncertainty and anticipate their responses to U.S. deterrence and assurance decisions. The analytical framework focuses specifically on the "human factors" involved in deterrence and assurance decisions, which need to be factored into the deployment and use of weapons and delivery systems in the complex strategic environment of the 21st century.

TAILORED DETERRENCE AND ASSURANCE: THE ANALYSIS OF HUMAN FACTORS

Kenneth Waltz (1959) has identified three main levels of analysis, which identify the locations of different causal mechanisms for the analysis of decisions to deter or assure and their consequences. Psychological mechanisms such as belief systems, motivational biases, and personality traits are located at the individual level of human nature. Social mechanisms, such as the type of government or economy, are domestic-level mechanisms at the level of society, while systemic mechanisms, such as the distributions of economic and military power among states, are located at the external level of the international system. In this appendix, the focus is primarily on social mechanisms and external situations that define situation-specific knowledge, while Appendix E will focus on the psychological mechanisms and internal dispositions of decision units that specify actor-specific knowledge.

In the top half of Figure D-1 the social psychology of mechanisms located at the external systemic, societal, organizational, and bureaucratic levels of analysis is characterized by roles (in bold) for Actor A and Actor B in which decision units are composed of individuals playing roles within a decision unit and in the larger strategic environment. In the bottom half of Figure D-1 the individual psychol-

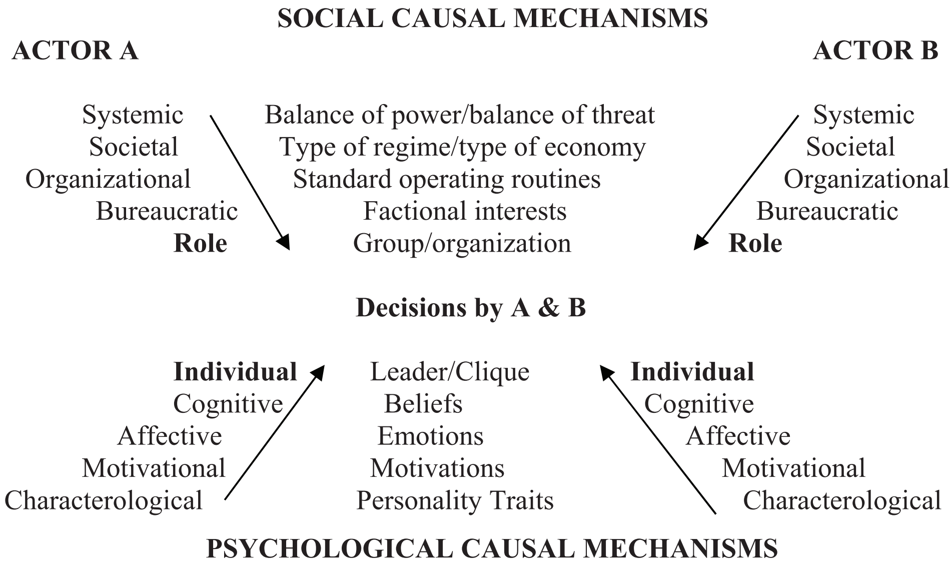

FIGURE D-1 Decision units and the funnels of social and psychological causality. SOURCE: Adapted from Campbell, et al. (1960); Waltz (1959); Allison (1969); Kegley and Witkopf (1982); Post (2003).

ogy of mechanisms located within each individual (in bold) are the processes that generate thoughts, feelings, and motives regarding the enactment of their roles in the strategic environment, which are the focus Appendix E. As one moves up the levels of analysis from the individual through the bureaucratic and organizational levels of the state and the society to the regional or global system, the locations of the causal mechanisms become more remote from the decision unit as the site of the decisions by Actor A to deter or assure and the decisions by Actor B to respond. However, they may still act to constrain the range of choices and perhaps even influence the actual choice of action.

Collectively, these mechanisms act as a funnel of causal forces and conditions that interact with mechanisms of the decision units to produce decisions by two actors (A and B), as shown in Figure D-1 (Campbell et al., 1960; Kegley and Witkopf, 1982). The relative influence of each level of social and psychological mechanisms is likely to vary by the type of decision-making situation. The remote social mechanisms may influence strategic decisions of general deterrence and assurance, which involve weapons procurement, development, and deployment and require more resources, time, and planning to implement (Trexel, 2013). The proximate psychological mechanisms may be more influential in crisis decision-making situations when stress from the situational features of surprise, high stakes, and short response time can influence immediate and extended deterrence and assurance decisions (Brecher and Wilkenfeld, 2000).

Graham Allison (1969) has identified three models of the social mechanisms in the upper half of Figure D-1, differentiated by distinct decision-making processes: rational choice processes at the external and societal levels (Model I), standard operating procedures at the organizational level (Model II), and bargaining processes at the bureaucratic level (Model III). Depending on which of these mechanisms dominates the decision-making process, the decision to deter or assure by Actor A and the decision to respond by Actor B may be the products of the processes of deliberation and choice associated with Model I; the organizational routines associated with Model II; or the consensus-building processes associated with Model III (Allison and Zelikow, 1999).

Post (2012) has suggested an additional decision-making model (Model IV) of the psychological mechanisms in the lower half of Figure D-1, which specifies a predominant leader's character, combinations of personality traits, and cognitive, affective, and motivational processes as important causal mechanisms. If an individual occupies a role in a decision unit where the individual's actions are indispensable in producing the decision, and if the decision maker's choice of action is idiosyncratic— that is, other individuals placed in the same strategic location would choose a different action then the individual's psychological decision-making mechanisms may be more powerful than the social mechanisms located in more remote sites in the funnel of causality (Greenstein, 1987).

To illustrate Model IV, consider the analysis by Sherman Kent, the founding father of the Central Intelligence Agency's (CIA's) Office of National Intelligence Estimates, who was tasked with understanding the reasons for the intelligence failure during the Cuban missile crisis to understand until too late that the Soviet Union was installing offensive missiles in Cuba. The U.S. government had found it difficult to believe that rational adversaries could take such a risky step. Kent concluded that insufficient attention had been paid to the personalities and political behavior of two key adversaries, Nikita Khrushchev and Fidel Castro. While they were not "irrational," they were both adventurous leaders with high risk-taking propensities, which were personality traits that were not given sufficient weight in understanding their likely behavior and the decision to install Soviet missiles in Cuba (Post, 2012).

The simplest kind of decision unit that meets the conditions of action and actor indispensability is the predominant leader decision unit, in which the power to decide rests in the hands of a single leader, such as Saddam Hussein in Iraq or Muammar al-Gaddafi in Libya and the Great Leader, Dear Leader, or Great Successor (Kim Il Sung, Kim Jong Il, or Kim Jong Un) in North Korea. External events and actions by others may also empower individuals: In crisis situations, for example, decision making may gravitate into the hands of a leader or a small, ad hoc group, which may become indispensable in making decisions insulated from the organizational and bureaucratic constraints associated with noncrisis decisions (Hermann, 1969, 1972; Brecher and Wilkenfeld, 2000; Allison and Zelikow, 1999; Schafer and Crichlow, 2010).[2] It is useful, therefore, to distinguish among both the different kinds of decision units and the situations in which they operate as decision units.

Studies of leaders, single groups, and multiple autonomous actors have revealed a common thread connecting their decision-making processes, which scholars have identified with different labels that tap the same variable namely, whether these different decision units are "open" or "closed" with respect to the external strategic environment (Rokeach, 1960; Rosenau, 1966; Kowert, 2002; Hermann and Hermann, 1989). Analyses of leader personalities identify open and closed minded individuals as extroverts or introverts (Rokeach, 1960; Etheredge, 1978; Kowert and Hermann, 1997; Kruglanski, 2004). Other analyses distinguish open and closed leader/advisor systems (Kowert, 2002; Hermann and Preston, 1994; Schafer and Crichlow, 2010; Hermann, 2003).

Analyses of different societies contrast open and closed regimes and economies as outward-looking or inward-looking (Rosenau, 1966; Solingen, 1998, 2007; Schaub, 2013). Analyses of international conflict and cooperation identify periods of relative inattention or attention in the relations between strategic dyads in the regional and global international systems (Deutsch, 1954; Deutsch and Singer, 1964; Waltz, 1959, 1964; Cobb and Elder, 1970; Solingen, 2007; Rasler et al., 2013). All of these studies focus at external systemic, societal, or state levels of analysis on whether the causal mechanisms in the decision unit (predominant leader, single group, multiple autonomous actors, or the state) operate to make it relatively "self-contained" or "externally influenceable" (Hermann and Hermann, 1989; see also Rosenau, 1966, and Solingen, 2007).

In a given crisis or conflict any one or a combination of the four models discussed earlier, Allison's Models I, II, III or Post's Model IV, may shed light on the manner in which decisions to escalate or de-escalate are made and expected. In addition, in acute international crises characterized by the elements of surprise, high stakes, and short time for decisions, it is likely that Post's Model IV will be all the more important to explain how decisions are skewed by personality traits, group dynamics, and fuzzy thinking caused by fatigue and acute stress. Crises such as the Cuban missile crisis are characterized by a threat to major values, ambiguous

[2] Not all predominant decision units are in autocratic regimes. Some democratic regimes assign this power to a leader on some issues, but the U.S. president has the decision-making authority to use U.S. nuclear weapons but shares power with others (in this case, Congress) on other nuclear decisions, such as acquisition of nuclear weapons.

or incomplete information, short time for decisions, and surprise (see Hermann, 1969, 1972; Brecher and Wilkenfeld, 2000).

Unfortunately, at such times when the smartest decisions need to be made, it is also the most difficult from a psychological standpoint. Crisis stress and fatigue may lead to emotionally distorted decisions. Such decisions under high anxiety are more likely to reflect groupthink, ethnocentric (or we-they) thinking, oversimplification, stereotyping, and premature conclusions before all the facts are considered. High stress can also cause a tendency in some leaders to freeze and become ineffective. Others indulge in mirror imaging and selective perception. Crisis decisions are also often made in small, ad hoc, face-to-face groups that can be influenced by group dynamics and a tendency to exhibit a risky shift phenomenon and conformity to group perspectives (groupthink) as well as decision momentum (Jervis, 1976; ‘t Hart et al., 1997; Schafer and Crichlow, 2010).

INTEGRATING HUMAN FACTORS IN DETERRENCE AND ASSURANCE DECISIONS

It is helpful in diagnosing and prescribing deterrence and assurance strategies and tactics to focus the attention of decision makers on those specific conditions that enhance the effectiveness of deterrence and assurance strategies rather than the conditions that make it more difficult to deter adversaries and assure allies. In order for a deterrence or an assurance message to be effective, it is necessary that the target of the message be *receptive* to it. Two general conditions of receptivity are that the recipient must be both willing and able to receive the message. If these conditions are weak or nonexistent, then the sender of the message will have to develop strategies to overcome these deficits or somehow work around them in order to deter or assure the recipient.

An effective strategy of tailored deterrence or assurance is designed to meet these two conditions. The first step in tailoring a deterrence or assurance message is to diagnose the situation-specific and actor-specific features of the strategic environment and decision unit, respectively, which indicate whether the relevant systems of interest are “open” (receptive) or “closed” (unreceptive) to the message being sent. The second step is to ask and assess whether or not these conditions effectively block the message. Depending on the answer to this question, the third step is either to send the message “as is” or devise a “work-around” strategy to overcome or otherwise neutralize the blocking conditions in order to communicate the tailored message. If it proves impossible or too costly to do so, then decision units should probably consider another means than deterrence or assurance and/or change their own goals in dealing with the adversary or ally.

It is also important to understand that the same conditions apply in effectively diagnosing and prescribing both deterrence and assurance decisions. The same decision may have both deterrence effects on adversaries and assurance effects on allies. The interdependence of these decisions has long been recognized by deterrence theorists in extended deterrence situations (Schelling, 1960, 1966; Jervis and Snyder, 1991; Khong, 1992). The most famous historical example of this analytical linkage is articulated by the Domino Theory, coined initially in the Eisenhower administration regarding the threat to the security of SEATO members posed by a communist seizure of power in Vietnam. This move would pose a geographical threat of communist invasion into neighboring states, such as Laos and Cambodia, which would fall like a row of dominos (Wolf, 1967). It also raises the issue of the credibility of U.S. commitments to deter and defend threats to other U.S. allies outside Southeast Asia during the Cold War (Schelling, 1966). These examples underline the interdependence of credible deterrence and assurance commitments: Deterring an adversary assures an ally, and vice versa, assuring an ally deters an adversary (Schelling, 1966).

An initial estimate of the degree of difficulty either in deterring an adversary or assuring an ally is a function of the answers to the questions posed in Figure D-2 about the targets of deterrence or assurance. The menu in Figure D-2 is a helpful tool as a decision-making heuristic or checklist in integrating the causal mechanisms to obtain a cross-level understanding of the likely degree of receptivity by the adversary or ally to deterrence or assurance decisions.

External Systemic and Domestic Societal Strategic Environments

System: attention (+) or distraction (−)?
Balance of power (+ or −)
Balance of threat (+ or −)

Society: outward (+) or inward (−) looking?
Regime (+ or −)
Economy (+ or −)

Characteristics of Decision Unit

State: outward (+) or inward (−) looking?
Multiple autonomous Actors (+ or −)
Single group (+ or −)

Individual: outward (+) or inward (−) looking?
Predominant Leader's Advisory System (+ or −)
Predominant Leader's Personality (+ or −)

Initial Overall Conditions of the Adversary or Ally

Degree of Receptivity: receptive (# of +'s) v. nonreceptive (# of –'s)?
Able: (System and Society) (+'s and –'s)
Willing (State or Individual): (+'s and –'s)

FIGURE D-2 Decision-making heuristics for deterrence and assurance decisions. NOTE: Open (+); closed (–). SOURCE: Waltz (1959); Hermann and Hermann (1989); Solingen (1998, 2007).

The mechanisms in the menu can each take two values: plus (+) or minus (−), which represent the binary states of "open" or "closed" for each mechanism. The binary values for each mechanism on the menu act as logic gates for assessing the likely response of the adversary or ally to the U.S. stimulus. The menu identifies potential necessary and sufficient conditions for the stimulus to elicit the desired response under the macrolevel conditions of human nature, domestic society, and the international system that either reenforce or mitigate the effects of the stimulus (Waltz, 1959). The state's organizational and bureaucratic mechanisms supplement the view of those macrolevel processes with a view inside the state of microlevel processes at the organizational, group and individual levels of analysis (Hermann and Hermann, 1989; Hermann, 2003; Post, 2003, 2012).

If the two initial logic gates of external system and society in the strategic environment are open (+), then the background conditions of the target are receptive to a deterrence or assurance message from the sender. These initial conditions at the external and domestic levels of analysis permit the target to receive a message from the sender. If one of the logic gates is open while the other is closed, then a deterrence or assurance message should be tailored toward the open gate. Depending on which gate is open, the message should be a military or an economic threat or promise. If both gates are closed, then it is relatively unlikely that the exercise of hard power based on military or economic resources will be effective, and the exercise of soft power through other means may be needed—for example, appeals to core norms of the target through diplomatic or cultural channels of communication (Nye, 1990, 2011).

The next level of analysis in Figure D-2 is the internal characteristics of the decision unit (multiple autonomous actors, single group, predominant leader and advisory system). It is possible for all three types of decision units to be present in a given society and accessible to messages from the sender (Rosati, 1981). It is also possible for decision makers at one of these levels of analysis to be receptive to a deterrence or assurance message even if the external conditions in the strategic environment are not receptive. The center of decision-making gravity may reside in one of them or be arranged in a hierarchical or a segmented configuration. It is possible as well for different decision units to be associated with different issues or situations.[3] Ideally, a deterrence or assurance message is targeted at a decision unit that is in the open condition and has the power to respond to the message.

[3] For example, in the U.S. case the separation of powers among executive, legislative, and judicial branches along with a bureaucratized executive branch may make the decision-making process more complex in some situations and more centralized in other situations (Hermann, 1969; Walker and Watson, 1992). In the U.S. case the power to make foreign policy decisions resides in both the White House and the Congress for some issues and situations while in others the White House has the power to make decisions.

The "ultimate decision units" (Hermann and Hermann, 1989) in any state are individuals who may decide alone or with others to respond authoritatively to a deterrence or assurance message.[4] It may be the case that a heterodox pattern of open and closed conditions exists inside the state at the levels of different decision units. Some individuals may be receptive to the message while others are not, which makes the exercise of deterrence and assurance power a relatively uncertain enterprise. In the end, it depends on (1) whether the external environmental situation permits a decision maker to be receptive, (2) the condition of the decision unit in which an individual or group resides is in a receptive condition, and (3) whether an individual is also psychologically in a receptive condition.

In particular, the relevant indices from content analysis techniques employed to study predominant leaders may also be useful for studying single groups and multiple autonomous actors as decision units. They may indicate whether these aggregate decision units as well as predominant leaders are in an open or closed condition. Generally, open decision units are more slow and deliberate while closed decision units are relatively fast and frugal in making decisions. Some configurations of decision units and situations can produce interaction effects leading to different types of risky decisions defined as extreme (risk-acceptant) rather than moderate (risk-averse) decisions (Hermann and Hermann, 1989). These possibilities are tabulated in Table D-1 for the four types of decision units.

The relevant indicators of open or closed conditions for predominant leaders are high or low integrative complexity; moderate or extreme needs for power, affiliation, and achievement; symmetrical or asymmetrical beliefs about the control of historical development by self and other; and non-zero-sum or zero-sum subjective games for self and other.[5] The analysis in Appendix E of these psychological

[4] Hermann and Hermann (1989, p. 363, n.1) define an ultimate decision unit this way: "If there is a decision, it is made by an individual, group of individuals, or multiple actors who have both (a) the ability to commit or withhold the resources of the government in foreign affairs and (b) the power or authority to prevent other entities within the government from overtly reversing their position without significant costs (costs which these other entities are normally unwilling to pay). We refer to the decision unit that has these two characteristics for a given issue at a particular time as the 'ultimate decision unit.'"

[5] Some of these indicators also interact with other personality traits to generate open or closed conditions: low need for power in combination with a low belief in historical control produces respect for external constraints, awhile a high need for power in combination with either a low or high belief in historical control produces challenges to external constraints. Different combinations of conceptual complexity and self-confidence interact to cause variations in openness to information (Hermann, 2003, pp. 188-195). Different combinations of power, affiliation, and achievement motivations are indicators of a decision unit's risk-averse or risk-acceptant orientations, as are different combinations of the instrumental operational code beliefs I-3, I-4a, and I-4b (Winter 2003; see also Walker et al., 2003). These indicators are discussed and illustrated in Appendix E.

TABLE D-1 Risk Propensity of Different Decision Units in Different States

Decision Unit	Internal States	Open/Closed System	Risk Propensity
Predominant leader	Contextual sensitivity	Insensitive (c) Sensitive (o)	Extreme Moderate
Single group	Degree of consensus	Agreement (c) Disagreement (o)	Extreme Moderate
Multiple autonomous actors	Relations among actors	Zero-sum (c) Non-zero-sum (o)	Extreme Moderate

NOTE: Open (o); closed (c).
SOURCE: Adapted from Table 1 in Hermann and Hermann (1989).

mechanisms concludes that these indicators are also likely to be valid for assessing the open or closed conditions of single groups and multiple autonomous actors.

In each instance and at each level within a decision unit, the key questions regarding receptivity are whether the conditions of *opportunity* (is the decision unit able?) and *willingness* (is the decision maker willing?) are present (Most and Starr, 1989). It is possible for the environment at each level to permit a response; however, the decision maker(s) may be unaware and/or unwilling (Sprout and Sprout, 1956; Kupchan, 1994; Walker, 2013). These uncertainties pose dilemmas in the form of crises of observation for the sender of the deterrence or assurance message. To whom should the message go and how should it be tailored?

A strategy of deterrence or assurance in this context refers to sending a message that recognizes the constraints and incentives in the recipient's strategic environment at the systemic and societal levels of analysis while navigating the organizational and bureaucratic constraints and opportunities inside the recipient's decision units. The response by a decision unit in the open condition is normally not an extreme decision that radically escalates or deescalates from the status quo. It is instead a pattern of decision making that is risk-averse rather than risk-acceptant and, therefore, is likely to be an incremental rather than a radical departure from the status quo (Braybrooke and Lindblom, 1963; Hermann and Hermann, 1989; see also Walker and Malici, 2011; Tuchman, 1984; Neustadt and May, 1986).

In the open condition a response is based primarily on information about the strategic environment and the sender's message rather than on structural biases and social mechanisms inside multiple autonomous actors or single groups as the decision units or unconscious psychological mechanisms in the decision-making processes of predominant leaders as the decision unit. Departures from the status quo are governed by the amount of information available to the decision maker; the less information available, the bigger is the uncertainty about the consequences of actions and the smaller is the opportunity and willingness to initiate bigger changes from the status quo. Conversely, the more information available, the bigger is the possible change because of the increase in certainty in a high-information environment about the consequences of various courses of action.

Since decision units normally operate in a complex environment with a relatively low information-processing capacity, they should be risk-averse and make moderate decisions. However, if decision units are closed and do not recognize the conditions of environmental complexity and low information due to the operation of psychological or social mechanisms, then they are prone to being risk-acceptant and making extreme rather than moderate decisions (Braybrooke and Lindblom, 1963; Hermann and Hermann, 1989; Walker and Malici, 2011).

TOOLS FOR MAKING TAILORED DECISIONS TO DETER AND ASSURE

There are four central research questions about deterrence and assurance strategies: (1) What deters and assures? (2) What military capabilities and optimal force postures are needed to provide deterrence and assurance effects? (3) What are the communications capabilities required to send effective deterrence and assurance messages? (4) What situation-specific and actor-specific knowledge is desirable to tailor effective deterrence and assurance messages? These four questions correspond to the three aspects of any deterrence or assurance strategy and the importance, identified by Bunn (2007), of tailoring the strategy.

In addressing these four questions it is important to recognize that the answers are interrelated. The answer to what deters or assures is that military capabilities can help deter and assure; however, they are neither a necessary nor a sufficient condition for deterrence success. As discussed in Chapter 2, a variety of influences may be necessary (diplomatic and economic among them), and, in some cases, deterrent efforts will fail even when the would-be deterer believes they should succeed. Another factor in success is the communications capabilities available to convince both adversaries and allies that military capabilities (and other aspects of influence) are available and ready for use against an adversary and on behalf of an ally.

The possibility of strategic deception in the form of convincing allies and adversaries that one has more military capabilities than is actually the case underlines the psychological character of deterrence or assurance success. A strategic surprise, such as the U.S. discovery after the invasion of Iraq in 2003 that Saddam Hussein did not have nuclear weapons, is always possible. Conversely, deterrence failure may occur even though the distribution of military capabilities may be asymmetrical in favor of the deterring power, because the putative deteree does not believe this information. In turn, the effective communication of military capabilities and the resolve to use them depends on the application of local knowledge of the situation and actors in question. However, admitting these strategic possibilities does not negate the central importance of military capabilities (actual or perceived) in taking credible deterrence or assurance actions, even if deterrence failure occurs due to domestic imperatives to attack anyway or doubts about the deterring power's credibility.

What Military Capabilities Deter and Assure?

Specifically, what are the optimal nuclear and conventional force postures for carrying out deterrence and assurance, including toward non-state actors as well as peers or near-peers and regional state actors? Schneider and Ellis identify seven classic elements of the U.S. deterrence strategy directed toward the Soviet Union during the Cold War:

- Having retaliatory forces capable of inflicting a level of damage considered unacceptable to the Soviet leadership,
- Possessing a second strike capability that could survive a surprise attack,
- Having a will to use this nuclear force in a confrontation if necessary,
- Communicating that the United States had both the will and the capability described so the U.S. threat was credible.
- Having an intelligence, surveillance, and reconnaissance system able to identify the origins of any attack, thereby answering the "who did it?" question,
- Having the capability to identify and strike a target set of the highest value to the Soviet Union and its leaders,
- Having a rational adversary leadership who preferred to live and stay in power rather than die in order to inflict destruction on the United States (Schneider and Ellis, 2012, pp. 462-463).

With the end of the Cold War and the emergence of multiple new nuclear powers led by decision makers with different cultures, personalities, historical experiences, and military capabilities, this Cold War deterrence strategy may not be optimal for all possible rivals, especially those far different from the Soviet Union, including some non-state actors (Lowther, 2013b; Trexel, 2013).

In particular, non-state actors like al-Qaeda may be significantly more difficult to deter than state actors since the former may have no known return address. Some of their followers may also be willing to martyr themselves in order to strike a blow against the far enemy—that is, the United States. A policy of deterrence by denial may be the most effective means of deterring a non-state actor's use of WMD. By keeping chemical, biological, radiological, and nuclear weapons out of the hands of such radical groups, they will be unable to strike a WMD blow.

Thus, it is desirable to deter such groups from acquiring WMD capabilities by adopting security measures to lock down so-called loose nuclear material, to make it more difficult to smuggle materials out of nuclear facilities worldwide, to increase surveillance of threatening groups, to take offensive actions against terrorist rings, and to provide a layered defense in depth against the transfer of WMD materials, WMDs, and persons of concern into the continental United States and allied territories. By making it more difficult to acquire WMD materials, to acquire the ability to transport and manufacture weapons from it, and to transport such arms and penetrate to significant targets, the U.S. can deny terrorists and other non-state foes the ability to destroy targets with such weapons.[6]

The Use of Game Theory

What if these kinds of efforts fail and nuclear proliferation occurs so that peers or near-peers, regional powers, and non-state actors acquire nuclear weapons? Game theory has long been a traditional tool for answering this question about capabilities along with operations research and systems analysis (Schelling, 1960; Ellsberg, 1961). Together with gaming possible scenarios in man/machine simulations, the representation of the logic of maximizing benefits and minimizing costs in strategic interactions with game theory is still a desirable research strategy for investigating the logic of deterrence and assurance against peers and near-peers, regional actors, and non-state actors in the 21st century security environment.

The 2×2 ordinal game (two players with two choices) is a mature tool in the repertoire of rational choice theories of decision making, including decisions for war or peace. It focuses on the deliberations and decisions of two rational players who realize that the outcomes of their decisions depend significantly on each other's choices and capabilities. Classical game theory models of this kind assume that both players make their choices based on the condition of two-sided information, i.e., that each knows the capabilities and preference rankings of both self and other for the four different outcomes generated by the intersection of their respective choices. With this information each player can calculate the optimum

[6] There are about 20 steps a non-state group would have to take to get and use a nuclear weapon in the United States. Such a group would have to acquire WMD material and then transport it outside of the state where it was stolen. Then the group would have to manufacture such an explosive and transport it to the United States passing through several layers of defenses designed to detect and intercept it. Finally they would have to successfully transport the finished nuclear weapon to the target area and employ it against a continental U.S. target. If the probability of each such step is assumed to be independent of the others in the process and if each step is reduced to just a 50 percent probability of success by taking defensive measures at each point in the 20-step process, then the chance of a successful terrorist nuclear attack would be reduced to less of than one in a million. If each step is assumed to be necessary, then failure at any one of the 20 steps could prevent the attack by itself. Of course, if the terrorist group were to steal a finished nuclear weapon and acquired an ability to detonate it, then the risk to the United States and allies would be much higher (see Mueller, 2010).

outcome and choose simultaneously on the basis of the two-sided information available to them.

Recent modeling efforts have analyzed theoretical solutions to the 2×2 game under conditions of *incomplete* information, when the players do not share accurate information about each other's preference rankings. Each is instead playing a different *subjective* game, and the outcome of their strategic interaction is the intersection of their choices based on their respective subjective games (Maoz, 1990; Walker et al., 2011). The rules of play also stipulate alternating rather than simultaneous moves based on information from revealed preferences inferred from prior behavior or pre-play communication between the players.

These two changes increase the likely external validity of the model and its usefulness for understanding adversaries and allies in deterrence and assurance situations in real-world interactions. The results of these more realistic games can identify the distribution of risk-acceptant and risk-averse paths forward for the United States and its adversaries and allies regarding the problems of deterring the escalation of conflicts and dissuading the spread of nuclear weapons and other weapons of mass destruction. A world of nuclear-armed powers in several regions increases the risk of escalation to a nuclear war from a conventional war and makes it desirable to focus increased attention on general deterrence and the dissuasion of nuclear proliferation, so that the occurrence of crisis and near-crisis situations involving extended and immediate deterrence actions are minimized.

Game theory provides a set of abstract models to represent the types of adversaries and allies that are possible in these security environments. The possible situations with the three types of actors (peers/near-peers, regional, and non-state actors) shown in Figure D-3 are represented as having different distributions of military capabilities in two types of strategic environments. The two players (U.S. and Other) rank their preferences from (4) highest to (1) lowest for the four outcomes (cells) where their choices of Cooperate (CO) or Conflict (CF) intersect as possible solutions to the game: mutual cooperation (CO,CO), mutual conflict (CF,CF), domination by one player and submission by the other player (CO,CF) or (CF,CO). For example, in the United States, peer/near- peer game, the (CO,CF) outcome of (1,4) is the lowest-ranked outcome of submission (1) for the United States and the highest-ranked outcome of domination (4) for Other. Conversely, the (CF,CO) outcome of (4,1) in the same game is the highest-ranked outcome of domination (4) for the U.S. and the lowest-ranked outcome of submission (1) for Other.

In a world of conventional weapons with peer/near-peer, regional, and non-state actors, the United States has the military capabilities to dissuade allies who are not assured by the U.S. strategy toward adversaries and, if necessary, dominate (CF,CO) or block (CF,CF) an adversary or ally if the other player refuses mutual cooperation (CO,CO) as the equilibrium solution. However, in the world of nuclear

			Adversaries					
			Peer/Near-Peer		Regional		Non-State	
			Other		Other		Other	
Strategic Environment		U.S.	CO	CF	CO	CF	CO	CF
	Conventional Weapons	CO	**4,3**	1,4	**4,3**	1,4	4,2	1,4
		CF	2,1	3,2	3,2	2,1	3,1	**2,3**
	Nuclear Weapons	CO	**4,3**	**2,4**	**4,3**	**2,4**	**4,2**	**2,4**
		CF	3,2	1,1	3,2	1,1	**3,3**	1,1

FIGURE D-3 U.S. games with types of adversaries in different strategic environments. The solutions from the Theory of Moves (TOM) are in bold (Brams, 1994). Cooperation (CO) and Conflict (CF) are the choices for each player, which can intersect and result in the following possible outcomes: mutual cooperation (CO,CO); row submits and column dominates (CO,CF); mutual conflict (CF,CF); row dominates and column submits (CF, CO).The logic of these conflict games also applies to allies who disagree with the U.S. strategy of ranking (CO,CO) as the highest outcome. Two players who agree on the highest-ranked outcome play a no-conflict game, with that outcome as the game's solution. SOURCE: Brams (1994, Appendix).

capabilities in Figure D-3 the U.S. ability to dominate (CF,CO) is in question, and deadlock (CF,CF) is a very risky outcome as both players in each game rank deadlock as the lowest-ranked outcome. In this strategic environment the risk of deadlock is nuclear war as the final outcome of a conflict, which would pose an existential threat to what each player wishes to protect.[7]

The solutions for all of these games with alternating moves and prior communication between players as the rules of play represent the logical outcomes in these two worlds if the United States chooses deterrence and assurance as its strategy

[7] This existential deterrent effect may have different referents in addition to or instead of the existence of the decision unit, such as family members, religious institutions, or a revolutionary movement that members of the decision unit hold dear. A deterrent threat will by definition not work against a completely nihilistic adversary who does not care whether anyone or anything survives a war.

for managing and resolving conflicts.[8] It is important to understand as well that deterrence/assurance is not the only strategy available to the United States in these two worlds. The focus here is on the logical consequences of a deterrence/assurance strategy, because this strategy is the current strategy of the United States and the mission of the U.S. Air Force.

The results in Figure D-3 illustrate the continued value of game theory as a tool to specify conflict situations with potential adversaries in which assumptions are made about the preferences of each player for the possible outcomes to the game. They show that if hard power (military capabilities) really matters, then the games (strategic interaction situations) against different types of adversaries have different outcomes for a deter/assure strategy of threats and promises by the United States. The U.S. outcomes depend as well on whether it is a world of conventional or nuclear weapons, even if the power position of the United States in the world changes or if the United States changes its strategy toward potential adversaries, because the introduction of nuclear weapons alters the ranking of each player's preference rankings for the possible outcomes of their games.

Finally, the results in Figure D-3 demonstrate how if the two players are truly strategic, that is, open to the information about their respective power positions in the world and aware of the nature of the outcomes of a nuclear war between them then when a CF,CF deadlock risking nuclear war is ranked lowest (1), the asymmetrical conventional superiority of the United State does not guarantee the outcomes of either settlement (CO,CO) or U.S. domination (CF, CO) as a solution to the strategic interaction problem. In a game of multiple equilibrium solutions, therefore, it is not always desirable in some cases for the United States to confront a nuclear adversary.

For example, a projection of the submission outcome (2,4) in Figure D-3 for the United States as the equilibrium solution in a nuclear strategic environment is a sufficient condition for the United States to consider disengaging militarily from this type of conflict situation under certain conditions of play against any type of

[8] In sequential game theory a strategy "is a complete plan that specifies the exact course of action a player will follow, whatever contingency arises" (Brams, 1994, p. 227). Strategies are distinguished and specified further here by the rank order of the four outcomes: mutual cooperation (CO,CO); mutual conflict (CF,CF); U.S. domination (CF,CO), U.S. submission (CO,CF). There are four families of strategies whose members share one of these four outcomes as the top-ranked outcome; members within each family of strategies are differentiated by variations in the rankings of the remaining three outcomes. For example, a deter/assure strategy ranks CO,CO as the highest ranked outcome. In Figure D-3, the U.S. deter/assure strategies in a strategic environment of conventional weapons rank CO,CO highest (4), CF,CF (3), CF,CO (2), CO,CF lowest (1) toward peers/near peers; the rankings are CO,CO (4), CF,CO (3), CF,CF (2), CO,CF (1) against regional and non-state actors. More generally, variations in rankings are specified by assumptions about differences in the distributions of power and interests between players (Walker, 2013).

adversary—peer/near-peer, regional, or non-state actor.[9] Instead, it should pursue its interests indirectly with soft power (diplomatic and economic tools of statecraft) to assure allies and isolate the adversary rather than employ hard power (military tools of statecraft) directly in an attempt to deter an adversary or dissuade an ally.[10]

It is important as well to acknowledge that these abstract, game-theoretic models may not have external validity. In the real world of historical cases between the United States and the three types of actors in Figure D-3, the assumptions in the model may not always be present. Each player may instead rank the four possible outcomes differently than the ones specified in this figure, or they may make decisions that are not based on information about all possible outcomes and the distribution of military capabilities between them. Specifically, if an adversary armed with nuclear weapons is not open (receptive) to deterrent threats, especially if backed into a corner with no way out, then it might elect to use those weapons first in a conflict for four reasons. First, the United States is very likely to win a conventional war, and defeat would mean the adversary state's leadership would lose power and perhaps their lives. Second, U.S. and allied airstrikes likely would force the adversary's leaders into a use-or-lose dilemma regarding their nuclear and other WMD capabilities. Third, the adversary might be tempted to use nuclear explosives to create electromagnetic pulse effects that would help level the playing field against a technically superior U.S. force. They might believe that since EMP was relatively bloodless, it might not provoke a nuclear response from the United States. Fourth, if an adversary was about to go down to defeat, it could elect to launch a revenge nuclear strike on U.S. forces, allies, and—in the future—against the U.S. homeland.

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[9] In the games in the nuclear strategic environment shown in Figure D-3 with multiple equilibria as stable outcomes, the actual final outcome depends on the order of play (who has the next move) from each possible initial state (cell) at the beginning of the game, whether preplay communication of threats and promises is allowed between the players, and whether the game is likely to be repeated between the two players (Brams, 1994). These conditions may not always favor the United States in an actual historical situation.

[10] The logical implications of these two strategies for exercising power directly or indirectly against an adversary are modeled with game theory in Walker and Malici (2011, Appendix, pp. 303-304).

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E

Tailored Deterrence and Strategic Intentions: Actor-Specific Knowledge for Deterrence and Assurance Strategies

INTRODUCTION

Can behavioral science research into the local knowledge of the personalities and cultures of state and non-state actors provide actor-specific knowledge for tailoring a U.S. communications strategy designed to deter adversaries, assure allies, and dissuade both adversaries and allies from developing, expanding, and using weapons of mass destruction (WMD) capabilities? This chapter discusses how actor-specific knowledge and the tools that can inform it—for example, leader personality profiling and both automated and expert-intensive content analysis, are useful for doing so, particularly in helping tailor communications with both adversaries and allies. They can help (1) assess whether the "decision unit" (predominant leader, single group, or multiple autonomous actors) is "open" or "closed" to receiving a deterrence or assurance message and (2) whether the decision unit is relatively risk-averse or risk-acceptant in its strategic orientation toward action.

WHICH COMMUNICATIONS CAPABILITIES DETER AND WHICH ASSURE?

The basic stimulus-response behavioral model of communications and information theory is relatively clear as a descriptive model (Shannon and Weaver, 1964;

Holsti et al., 1968). A message in the form of an action (e.g., a threat or promise) is sent by Actor A as the stimulus (S). Actor B receives this message and follows with a response (R) in the form of cooperation or conflict behavior. Social scientists have scales and indices that can measure (S) and (R) to see if there is congruence between them, i.e., whether S and R "match up" (correlate) in the way intended by Actor A. If so, then the outcome is deterrence or assurance success, and if not, then the outcome is deterrence or assurance failure.

However, it is not so clear what the intervening causal processes are that account for the correlation between S and R, or how these explanatory models can be specified and measured. The conventional model in the classical deterrence literature assumes a causal mechanism of "economic rationality," in which costs (c) and benefits (b) are calculated by Actor B. For the simple case of B having only the choices of escalating or deescalating, then if (c) > (b) regarding escalation (e) and if (b) > (c) regarding de-escalation (d), then Actor B will choose deescalation (d) (see Ellsberg, 1961; Robbins, et al., 2013). Unfortunately, it is difficult both conceptually and empirically to define and measure (c) and (b) with reasonable reliability and validity. In addition, there are problems, discussed in Chapter 2 of this report, such as the actors may not in fact have stable utilities and may not base their actions on "expected-value" calculations as assumed by the original notions of economic rationality.

Another basic assumption in rational choice models of deterrence and reassurance is that the both Actor A and Actor B understand the costs and benefits in the same way. These assumptions are at best first approximations and, at worst, they are radically wrong under real-world circumstances in which threats and promises may be exchanged between Actor A and Actor B but are communicated or interpreted ineffectively. Motivational and emotional biases, such as fear, anger, or mistrust, and cognitive biases, such as ideological beliefs or cultural norms, may distort the identification, weighting, and calculation of costs or benefits.

The result is a choice that follows rational procedures in the sense of actors trying to relate ends and means, but it may be unwise because of distorted perceptions at the point of decision (Post, 2003a; Downes-Martin, 2013; see also Holsti et al., 1968; Zinnes, 1968; Holsti, 1972; Jervis, 1976; Fiske and Taylor, 1991; Davis and Arquilla, 1991; Steinberg, 1996). The influence of these actor-specific factors is heightened under certain stressful decision-making conditions when a crisis situation, defined as a surprise involving high stakes with a short time in which to respond, is the occasion for decision (Hermann, 1969, 1972; Brecher and Wilkenfeld, 2000).[1]

[1] Deterrence theorists also recognize shortcomings of the rational choice mechanism connecting threats and responses (Morgan, 2003). It is often argued that the value of the rational choice model lies in its value as a normative standard against which to assess what is actually occurring in strategic

These problems are compounded when the mechanisms connecting S and R are social as well as psychological. If multiple actors are involved rather than a single predominant leader, then results may depend on complex interactions among the various individual cost-benefit equations, as well as the effects of imperfect communications and power relationships. The results may therefore be unpredictable. To put it differently, trying to open the black box and understand the intermediate causal mechanisms leading to a decision inside a predominant leader, within a single group, or among a coalition of autonomous actors may not be feasible by outside observers, especially if they lack the tools for decoding their interactions and organizational context (t'Hart et al., 1997; Schafer and Crichlow, 2010; Allison and Zelikow, 1999).

A strategy of tailored deterrence and assurance attempts to reduce the gaps between the rational model implying desired results and the psychological and social mechanisms that generate the actual results. The particular emphasis in this chapter is on the psychological mechanisms of object appraisal, mediation of self–other relations, and ego defense identified in Appendix D (see Figure D-1).[2] The basic communications problem to be solved is reducing the problem of uncertainty in the decision-making environment for Actor A in dealing with Actor B as an adversary or an ally. There may be uncertainty about the capabilities, goals, or intentions of Actor B. In the absence of direct and updated evidence (new information) about these items, decision makers in Actor A may substitute beliefs (old information) inferred vicariously from lessons learned in previous personal encounters or analogous situations (Jervis, 1976; Neustadt and May, 1986; Larson, 1985; Vertzberger, 1990).

The recall of this information may be accompanied by undesirable emotional tags in the form of the arousal of motivations or feelings that were actually stimulated earlier by the actions of the other actor and shaped the recall of inappropriate analogies (De Rivera, 1968; Jervis, 1976; Zajonc, 1980; Steinberg, 1996; Post, 2003a; Marcus, 2003; Neumann et al., 2007; Downes-Martin, 2013). Therefore, it can be important for Actor A to know B's psychology as well as B's sense of power balances and utilities, in order to tailor the communication of a threat or promise

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interactions and then taking steps to share more information and thereby increase the chances of a rational response and outcome in subsequent interactions (Fearon, 1994a,b; Zagare and Kilgore, 2000; Glaser, 2010). The debate over whether and how the actual mechanism needs to be specified correctly in order to understand how deterrence works is the subject of a symposium in *World Politics* (Downes, 1989), an edited volume by Geva and Mintz (1997), and a book by Morgan (2003). As discussed in Chapter 2, another view is that the economic-rationality model is not necessarily a good normative model and is certainly not descriptive: Different decision styles are appropriate, not just common, in different types of circumstances.

[2] The social mechanisms also identified in Figure D-1 were discussed in Appendix D.

accordingly. What are the available profiling methods and tools for accessing this psychological knowledge?

An individual's basic personality characteristics are relatively stable traits that are inherited genetically and shaped into different configurations or syndromes by childhood and adolescent psychobiographical experiences; they are relatively constant and not likely to change without psychiatric treatment or perhaps genuinely life-altering experiences (Post, 2003a). However, these structural characteristics of the personality system are not all equally relevant for explaining political behavior, as different situations are likely to selectively engage aspects of the basic personality system as causal mechanisms (Funk et al., 2013). For example, an individual with a narcissistic personality syndrome that is characterized by a motivation to seek glory and adulation from others to compensate for underlying self-doubts may be more likely to seek careers in the public arena of politics as well as other venues of social life where a leading role is available.

In immediate political situations these enduring structural personality characteristics may act as unconscious influences that condition the range of options a leader considers, and they perhaps influence the actual choice of actions in ways that outside observers would deem "radically irrational"—that is, as triggered and driven by unconscious emotional and motivational impulses unmediated by conscious thoughts and beliefs and information available from the environment (Simon, 1985). While constant features of a leader's personality structure may define the character of the leader and influence all of his political decisions, three questions also arise: How exactly do these structural features of the personality system influence a decision? Is it a matter of kind or degree? When (in what situations) do they matter and at which stages in the decision-making process are they relatively unimportant?

There are two ways to answer such questions in linking personality with decisions: (1) pursue a top-down strategy that defines the leader's basic personality structure from psychobiographical evidence remotely located from the occasion for decision and then examine how proximate processes of cognition, emotion, and motivation associated with an immediate decision-making situation link personality structure with political behavior or (2) pursue a bottom-up strategy that first examines those proximate processes that are direct causal mechanisms of behavior in the immediate decision-making situation and then contextualize these results by linking them with the underlying structure of the leader's personality.

These two approaches characterize the leadership profiling literature in political psychology and are illustrated in this chapter with their application to the personality of Iraqi leader Saddam Hussein in the decision-making situations that he faced in the 1990-91 Persian Gulf conflict with the United States and its allies. The example of the Persian Gulf conflict includes efforts by the U.S. government to deter an attack on Kuwait by Iraq and subsequently to coerce Iraq's withdrawal from Kuwait. The following analysis presents brief illustrations of several profiling methods for analyzing actor-specific knowledge relevant for making tailored deterrence and assurance decisions. The examples all draw on the case of Saddam Hussein as a predominant leader who was neither deterred from invading Kuwait in 1990 nor persuaded to withdraw voluntarily in 1991.

The first example is a summary of the top-down, holistic study of the Iraqi leader Saddam Hussein by Post (2003b), which was presented in testimony before the House Armed Services and Foreign Affairs Committee in December 1990. The method employed in this study is the use of available historical and psychobiographical sources to construct a political personality profile of a leader's basic personality type, such as one of the three examples in Table E-1.

TABLE E-1 Examples of Types of Basic Personality Structure and Leadership Styles

	Example of Political Personality Types		
Mechanism	Narcissistic	Obsessive-Compulsive	Paranoid
Ego defenses	Grandiose self, sense of superiority, and denial.	Abhorrence of emotionality that implies lack of control.	Suspiciousness and mistrust
Externalization	Projects arrogance and grandiose self-image. hypervigilance.	Projects fixation with rules, order, efficiency, isolates, rigid, sublimates, intellectualizes.	Projects hostility and stubborn
Mediation of self–other relations	Hunger for reassurance and vulnerability to criticism, lacks empathy. Exploitative, sense of entitlement.	Preoccupied with relative status, is oppositional or domineering. Formal, over moralistic, micro- manages, does not delegate.	Fear of closeness, projection, search for enemies and distrusts all.
Object appraisal	Dogmatic certainty and manipulation of information.	Attention to detail and insistence on rational information processing. Less aware of big picture.	Exaggerates danger and capabilities of adversaries. Black and white thinking.
Decision-making orientation	Risk-averse and dominated by centrality of self. Identifies self-interest with country.	Risk-averse and perfectionistic with decisions avoided, deferred, protracted, and based on expertise.	Risk-averse and worst-case thinking based on competitive advisors.
Leadership style	Search for glory and recognition	Driven, deliberate, myopic, dominated by shoulds, not wants, and search for certainty	Strongly prefers use of force over persuasion.
Prototype	Saddam Hussein	Menachem Begin	Josef Stalin

NOTE: The personality characteristics in this table are representative, but they do not exhaust the defining features of each personality type.
SOURCE: Based on information from Post (2003a).

Iraq under Saddam is an exemplar of a society with a predominant leader. In such situations, it is imperative to have a nuanced personality profile of the leader. As was regularly stated, "Saddam is Iraq, Iraq is Saddam" (Post, 2003b, p. 343). Post diagnosed Saddam Hussein's basic personality type as "malignant narcissism" (a narcissist with a paranoid outlook, absence of conscience, and a willingness to use whatever aggression is required to accomplish his goals). While psychologically in touch with reality and not "crazy" in a clinical sense, Saddam was often out of touch with political reality. He was surrounded by a group of sycophants who, for good reasons, were reluctant to criticize his decision making and told him what he wanted to hear rather than what he needed to hear. To disagree with Saddam was to lose one's job or lose one's life (Post, 2003b).

An examination of Saddam's career reveals a number of occasions when he reversed course, considering himself a "revolutionary pragmatist" (Post, 2003b). Why then was Saddam, who was characterized as risk-averse, not deterred from invading Kuwait? Further, why was he not responsive to coercive diplomacy by the United States in the form of a massive military buildup and threatened air campaign as the January deadline approached for him to withdraw Iraqi forces from Kuwait? Why did he not reverse himself as he had in the past and withdraw from Kuwait? [3]

With intelligence indicators and warnings that Saddam was planning an invasion of Kuwait and Iraqi troops massing on the border, U.S. Ambassador April Glaspie was instructed to inform Saddam that the United States considered the territorial dispute between Iraq and Kuwait to be an Arab-Arab dispute and that the U.S. government did not take a position on it. She was to be clear in expressing the hope and expectation that Iraq and Kuwait would settle their differences peacefully. There was no overt threat of a U.S. military response should Kuwait be invaded. Glaspie's message did not represent a clear cease-and-desist message (Schneider, 2012). Although Saddam did not see the *demarche* as a green light to invade Kuwait, he also did not calculate accurately the risk of a massive U.S. response to Iraq's invasion of Kuwait (Freedman and Karsh, 1993, pp. 47-61). [4]

[3] Saddam's past course reversals include (1) yielding on the Shatt al Arab issue with Iran to quell Kurdish rebellion; (2) attempting to end the Iraq-Iran war; (3) yielding to Iran on the Shatt al Arab waterway issue to end their war; (4) releasing all foreign hostages during Persian Gulf crisis. See Post (2003b, pp. 340-342).

[4] It was not only that the Glaspie message contained no threat. The United States had not deployed aircraft carriers to the region, and it seemed unlikely that even if it wanted to act militarily, it could not do much because the Saudis would not accept U.S. forces. Further, it seemed that the United States did not have much stomach for casualties, as evidenced by Vietnam and the pull-out of forces from Lebanon. Saddam also greatly underestimated the effects of modern air power and had no idea how totally over-matched his ground forces were. Even though he seems to have rationally contemplated risks, he underestimated them greatly while at the same time having grandiose ambitions. For other discussions of Saddam's potential and actual thinking, see Davis and Arquilla (1991), Stein (1991), and Brands and Palkki (2012). The analysis of Saddam Hussein's perceptions and misperceptions by

I. Historical Antecedents
Iraq suffers from foreign rule, succession of revolutionary regimes, and Iran-Iraq War.

II. Childhood Experiences as Development Context
Mother abandons Saddam, who suffers abuse from stepfather. Uncle tutors young Saddam in Baathist worldview and dreams of glory, compensating for low self-esteem from earlier abuse and abandonment.

III. Personality Processes and Dispositions

Ego Defense
Unconstrained conscience.
Unconstrained aggression.
Paranoid orientation.

Externalization and Projection
Identifies self with Iraq.

Mediation of Self and Others.
Adopts the "great struggler" role against Zionism, Iran, and West.

Object Appraisal
Overestimates Iraqi and underestimates U.S. power and resolve.

IV. Immediate Situation as Occasion for Action
Saddam's advisors reluctant to disagree with his plans. Arab and Israeli neighbors' beliefs that Saddam was posturing or bluffing. No explicit U.S. deterrent threat.

V. Political Behavior
Iraq invades Kuwait and exults in world attention. U.S. threatens to expel Iraq from Kuwait. Iraq first resists and then retreats as U.S.-led coalition attacks.

Past ⟶ **Present**

FIGURE E-1 Map of Saddam Hussein's political personality and behavior. NOTE: The map's narrative locations are numbered left to right in temporal order from I to V. SOURCE: Based on information from Post (2003b); map adapted from Smith (1968) in Greenstein and Lerner (1971, p. 38).

Following Iraq's invasion and occupation of Kuwait, however, U.S. intentions were not ambiguous. If Iraq did not withdraw from Kuwait, the United States threatened the massive destruction of Saddam's military might. This threat was communicated not only with mere words, but with evidence on the ground in Saudi Arabia and the Persian Gulf of a massive U.S. buildup preparing for military action. To understand why Saddam stood fast in the face of this imminent threat, one must consider the psychodynamic effects of the conflict thus far on Saddam, and the psychobiography-based political personality profile predicting Saddam's likely behavior summarized in Figure E-1 and discussed below.

As the map in Figure E-1 shows, this perspective highlights Saddam's background as one of a deeply traumatized individual, a wounded self, dating back to the womb. Saddam's father had died of cancer during the fourth month of his mother's pregnancy with Saddam. In the eighth month, her first born son died under a surgeon's knife. Understandably deeply depressed, Saddam's mother first tried to abort herself of the pregnancy with Saddam and then made a suicide attempt. When Saddam was born, she turned away from him and finally gave his care to her brother Khairallah, who raised Saddam for the first two and a half years of his life, when his mother remarried and the new step-father was physically and

Woods and Stout (2010) reflects extensive documentary material gathered after the 2003 war with Iraq.

psychologically abusive to young Saddam. At age 8, when his parents refused Saddam's request to go to school, he fled back to his uncle Khairallah (Post, 2003b).

His Uncle Khairallaha filled young Saddam with dreams of glory, telling him some day he would be listed among the great heroes of Iraq and the Arab world, Saladin and Nebuchadnezzar. The dramatic invasion of Kuwait, which drew the attention of the world to the Iraqi leader, consummated his aspiration to be an important world leader, nurtured since childhood and accompanying his rise to regional prominence in the Middle East. It was dreams of glory fulfilled. As a narcissistic personality he could not then easily reverse himself without opening old psychological wounds unless there was a way that he could declare victory and withdraw (Post, 2003b).

So the notion that Saddam Hussein would respond to threatened military action and, humiliated, retreat from Kuwait to his previous obscurity was not intuitively obvious. He had reversed himself in the past; however, these reversals had only occurred when he could do so without loss of face while retaining his power.[5] By mid-December, 1990 Saddam Hussein was adamant and had resolved to stand fast. When Secretary of State Baker had his last-minute diplomatic visit with Iraqi Foreign Minister Tariq Aziz, he found that Saddam Hussein was no longer open to complying with a U.S. compellent threat to withdraw or face expulsion by military force (Post, 2003b; Schneider, 2012).

The second type of analysis is a bottom-up approach that focuses on the proximate causal mechanisms of ego defense, externalization, mediation of self–other relations, and object appraisal under Personality Processes and Dispositions in Figure E-1 that connect a leader's personality traits, motivations, and cognitions

[5] This condition was not met when U.S. President George H.W. Bush pounded on a table, declaring, "There will be no face saving," and a leak from a U.S. general (subsequently forced to retire early) indicated that the U.S. contingency plans were to kill Saddam. In this context, it was not irrational for Saddam to believe that he did not have a way out of the conflict with the United States. Moreover, his decision to absorb the anticipated massive airstrike was buffered by his belief that the United States still suffered from a Vietnam syndrome, and if he could withstand the airstrike and get involved in a ground campaign, the specter of U.S. troops being returned in body bags would lead to massive U.S. protests against the Pentagon and White House, leading to a political stalemate. Saddam, by having the courage to stand up to the U.S. superpower, would win a hero's mantle. Indeed, on the fifth day of combat, Saddam held a press conference and declared victory. It was explained to the incredulous press that it was widely believed that Iraq could not withstand more than 3 days of the air attack with smart bombs and guided missiles, and had already survived for 5 days. Each further day would only magnify the scope of the victory (see Post, 2003b). Saddam Hussein had stated previously in an interview on German television the belief that the United States would end the conflict once they had lost 5,000 or more killed in action, which unfortunately for the Iraqi leader did not happen (see Schneider, 2012, p. 217). RAND work at the time also foresaw Saddam's being willing to fight but, if necessary, to find a way to exit later if need be. The analysis was influenced by the belief that Saddam would assume that the U.S. would violate any agreement; other considerations were also part of the analysis (Davis and Arquilla, 1991, pp. 53-61; see also Brands and Palkk, 2012).

with decisions and leadership style within the boundaries set by the leader's character. The method employed to study these mechanisms is quantitative content analysis, which detects variations in the operation of these causal mechanisms, in contrast to qualitative content analysis, which identifies character structure as a constant in a leader's personality. The tools associated with quantitative content analysis are scales and indices that summarize the central tendency and range of variation over time in the cognitive, motivational, and other psychological traits in a leader's personality.

In contrast to a leader's character, these features of the leader's personality are relatively more plastic features that change shape over time in response to changing environmental conditions. While different leaders may have different structural configurations of personality traits that transcend situations and define character, a leader's individual personality traits also become aroused in different degrees and combinations, depending on environmental stimuli. So Leader A's significant difference from Leader B in self-confidence may remain robust across situations, but the intensity and influence of self-confidence in combination with other personality traits on behavior may vary for each leader in the same situation.

Similarly, different situations arouse different motivations within a leader's personality—for example, a conflict situation with adversaries may engage a leader's need for power, while a cooperation situation with allies may arouse a leader's need for affiliation (Winter, 2003a). The same is true for a leader's cognitions, because different configurations of beliefs and levels of cognitive complexity may be triggered as mechanisms to assist a leader's information processing and decision-making in different situations (Suedfeld et al., 2003; Walker, 2013).

Saddam Hussein's personality traits associated with the externalization of his leadership style via his motivational and cognitive processes associated with the mediation of self–other relations and object appraisal displayed these variations across different periods and situational contexts preceding, during, and following the 1991 Gulf war. In Figure E-2, his mean scores on seven personality traits differentiated him from the average Middle East leader and the average world leader: "Saddam Hussein is different from the two samples of leaders on over half of the traits—nationalism, need for power, distrust of others, and self-confidence. He is like other leaders with regard to his belief that he can control events, conceptual complexity, and his focus on accomplishing something versus focusing on the people involved… " (Hermann, 2003b, p. 376).

The four traits that distinguished the Iraqi leader from others also varied significantly across contexts. His conceptual complexity was significantly lower (.27) in the 1991 Gulf War period in contrast to the pre-Iranian War (.50) and Iran-Iraq War (.55) periods. The nationalism trait was significantly higher (.72) in the Gulf War than in his relations with either Arabs or non-Arabs (.58). His need for power (.39) was strikingly lower in domestic politics and during the Gulf War than the

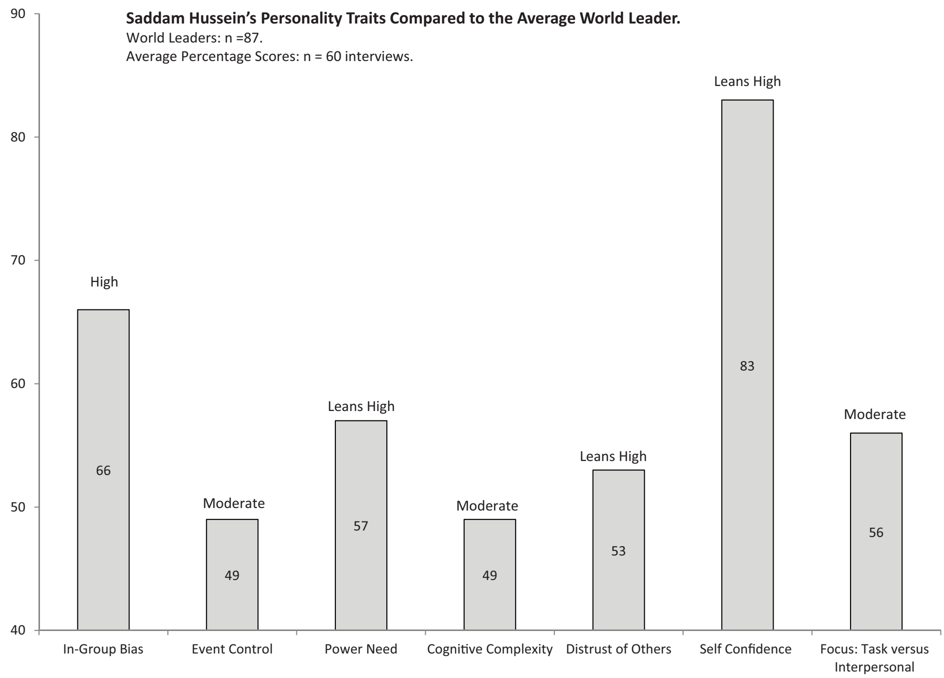

FIGURE E-2 Fluctuations in Saddam Hussein's personality profile. SOURCE: Based on Post (2003a); data from Table 17.1 in Hermann (2003b).

range of his need for power scores (.53 to .69) in dealing with the Kurds and relations with both Arabs and non-Arabs. His distrust of others was elevated during the Gulf War (.68) and the Iran-Iraq War (.66) periods and in dealing with the Kurds (.65), in contrast to domestic politics (.39) and relations with both Arabs (.44) and non-Arabs (.49), which had lower scores (Hermann, 2003b, p. 383).

Saddam Hussein's motivational profile regarding the needs for power, affiliation, and achievement over a 17-year period between 1974 and 1991 showed that he had a "quite high power motivation, above average affiliation motivation, and very low achievement motivation" in comparison with the average world leader in a sample of 22 world leaders from a variety of geographical regions occupying different political roles (Winter, 2003b, p. 371). The results in Figure E-3 from a content analysis of 11 interviews are relatively stable when broken down by different sources (more versus less spontaneous interviews). The results are consistent with Post's structural personality profile that emphasizes Saddam's "extreme narcis-

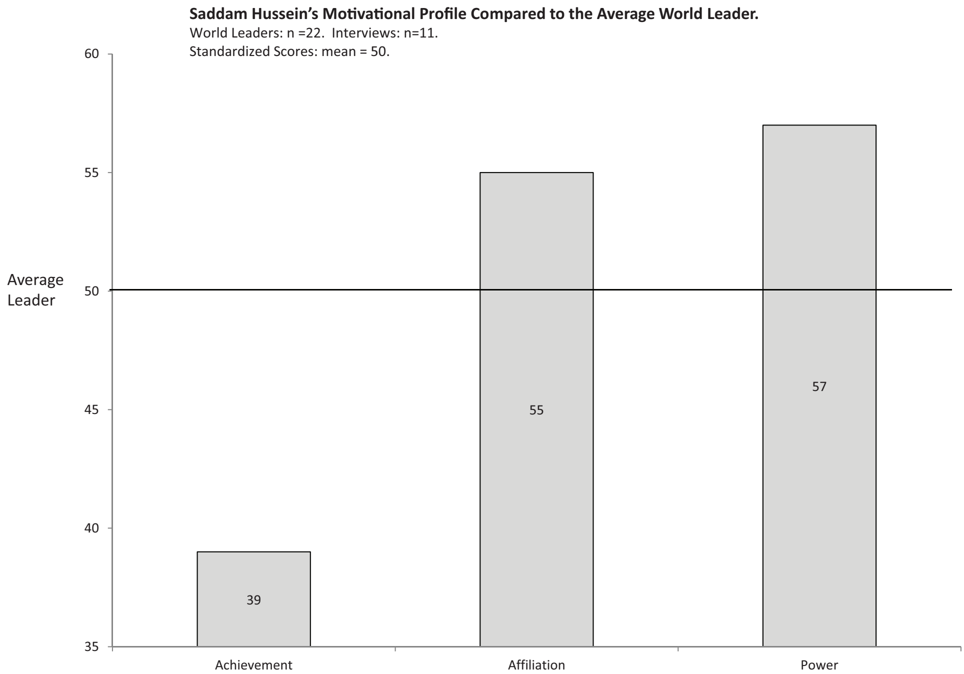

FIGURE E-3 Saddam Hussein's motivational profile. SOURCE: Based on Post (2003a); data from Table 16.2 in Winter (2003b).

sism, exalted and extravagant rhetoric, aggression as an instrument of policy, and a paranoid fear of enemies" (Winter, 2003b, p. 372).

The two-point difference between the Iraqi leader's power and affiliation scores is also consistent with Hermann's observations of fluctuations in Saddam's personality traits aroused in his relations with different "others" in different situations. His high need- for-affiliation score indicates a capacity to cooperate with an in-group of like-minded people from his own family and village and be defensive and "prickly" in the wider world of Iraqi politics and foreign strangers. The same dynamic characterizes Saddam's relations with "brother" Arabs and his defiant and hostile relations with adversaries in stressful crisis situations (Winter, 2003b, p. 373).

The same patterns of and volatility and stability that characterize the externalization of personality traits and the mediation of self–other relations regarding motivations are evident in the object appraisal patterns displayed in the cognitive complexity patterns of Saddam Hussein in Figure E-4. The processes of object ap-

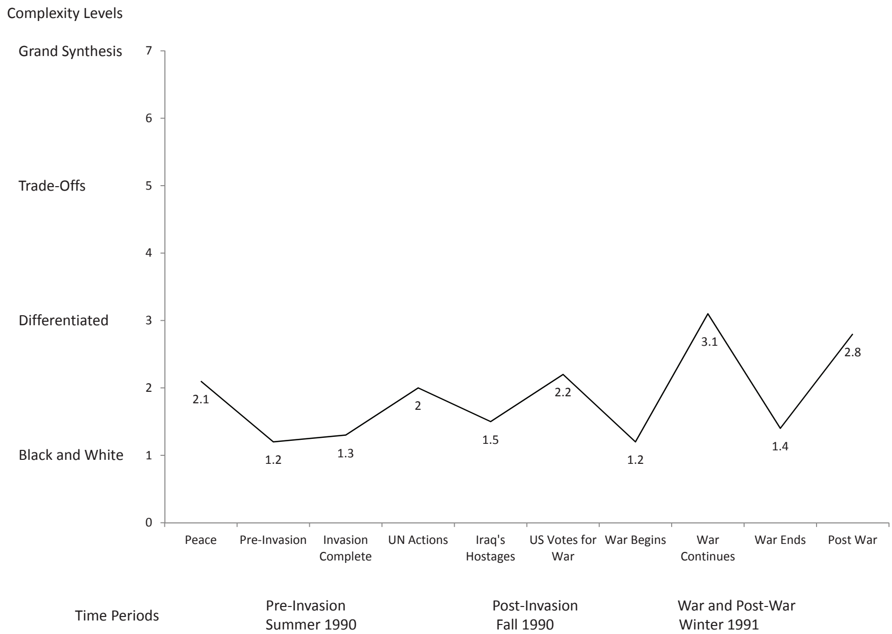

FIGURE E-4 Saddam Hussein's Gulf War patterns of cognitive complexity. SOURCE: Data from Table 18.2 in Suedfeld (2003).

praisal are the most conscious causal mechanisms in the leader's personality system and reflect how overt decisions are reached to pursue or maintain goals and select the means to achieve or protect them.

Saddam's cognitive complexity scored lower during the Gulf crisis (not shown in Figure E-4) leaders of other less-involved nations. "This finding supports the disruptive stress hypothesis, which states that severe and/or prolonged stress leads to reduced complexity because of a depletion of psychological and other resources" (Suedfeld, 2003, p. 393). However, prior to the Gulf crisis, Saddam's complexity was relatively high. It then dropped immediately prior to the decision to invade Kuwait, before rising after the invasion was successful and his stress level had decreased (Suedfeld, 2003, p. 393).

The cognitive complexity indices for Saddam Hussein in Figure E-4 continued to be relatively volatile during the ensuing confrontation with the United States and UN coalition forces. The overall pattern is consistent with Post's "great struggler" finding as Saddam's political role in Middle East and global politics. "New actions against him, rather than motivating him to search for compromise, buttress a unidimensional strategy; more cognitive investment in a differentiated and integrated viewpoint occurs when it becomes obvious that the simple strategy is unavailing" (Suedfeld, 2003, p. 395).

This pattern of stubborn resilience, as shown in Figure E-4 during the run-up to war following his invasion of Kuwait, was punctuated by sharp drops in complexity levels with the onset of the air and ground war attacks on Iraq and the defeat of the Iraqi army by coalition forces before rising to a prewar level with the beginning of postwar restructuring inside Iraq. Overall, the cognitive complexity results in Figure E-4 express his cognitive style and reflect variations in Saddam Hussein's level of cognitive effort during the Persian Gulf conflict, as he attempted to reconcile stimuli from the environment with the cognitive dispositions in his belief system (Suedfeld, 2003).

An example of the contents of the Iraqi leader's beliefs is in Table E-2 and identifies a snapshot of his "operational code"—that is, his state of mind at a particular point in time regarding the exercise of power by Self and Others. It also contains an index of Saddam's risk orientation regarding interaction with others in the political universe plus his beliefs about risk management tactics and the utility of different forms of political power as means in the pursuit of goals. The analysis in Table E-2 compares Saddam's beliefs to a sample of world leaders from a variety of historical eras and regions. These scores are expressed in terms of standard deviations from the sample's average for each belief.[6]

The results show that Saddam believed that the most effective strategies (I-1 = −1.24) and tactics (I-2 = −1.08) for exercising power were definitely conflictual; however, he was very risk averse (I-3 = −1.71) and controlled the risks of escalation by being extremely flexible in shifting between cooperation and conflict tactics (I-4a = +2.40) and very flexible in shifting between word and deed tactics (I-4b = +1.60) in the exercise of power. He believed that the utility of exercising rewards and punishments was somewhat high (I-5a = +0.40) while the utility of exercising promises (I-5b = −4.67) and threats (I-5e = −3.00) was extremely low. His belief in the utility of opposition and resistance tactics was very high (I-5d = +1.71) while his belief in the utility of appeal and support tactics (I-5a = 0.00) was the same as that of the average world leader (Walker et al., 2003b pp. 388-389).

The VICS indices for I-1, P-1, and P-4 are the basis for constructing a formal model of strategic interaction, which expresses the leader's definition of the strate-

[6] A deviation is the distance between a leader's score and the average score for the norming group sample. A standard deviation is the distance around the sample mean within which two-thirds of the scores for the entire sample fall. When a leader's score has a standard deviation above (+) or below (−) the sample mean greater than one standard deviation, it indicates that s/he has a score higher (+) or lower (−) than two-thirds of the sample. The words "Somewhat", "Definitely", "Very", and "Extremely" to describe the standard deviation scores are applied in Table E-2 to half-standard deviation intervals above or below the mean score of the norming group sample for each VICS belief index (see Walker et al., 2003a).

TABLE E-2 The General Operational Code and Subjective Game of Saddam Hussein

General Operational Code	VICS Indices[a] Std. Dev	Descriptor
Philosophical Beliefs		
P-1 Nature of the political universe	–1.47	Very hostile
P-2 Prospects for realization of political values	–1.33	Very pessimistic
P-3 Predictability of the political future	–4.67	Extremely low
P-4 Control over historical development		
a. Other's control	–3.80	Extremely low
b. Self's control	+3.80	Extremely low
P-5 Role of chance	+4.00	Extremely high
Instrumental Beliefs		
I-1 Approach to goals	–1.24	
I-2 Pursuit of goals	–1.08	
I-3 Risk orientation	–1.71	
I-4 Timing of action		
a. Flexibility of coop/conf tactics	+2.40	Extremely high
b. Flexibility of word/deed tactics	+1.60	Very high
I-5 Utility of means		
a. Reward	+0.40	Somewhat high
b. Promise	–4.67	Extremely low
c. Appeal/support	+0.00	Average
d. Oppose/resist	+1.71	Very high
e. Threaten	–3.00	Extremely low
f. Punish	+0.60	Somewhat high

Saddam's Subjective Game			**US Deter/Assure Game**			**Intersection of Two Games**		
	Other			US			US	
	CO	CF		CO	CF		CO	CF
CO Self	3,2	**2,4**	CO Iraq	**3,4**	**2,3**	CO Iraq	2|0	1|0
CF	4,1	1,3	CF	4,1	1,2	CF	2|0	2|2
Self Bluff; Other: Bully			Iraq Bluff, US: Deter			Expl|Act Row Outcomes[b]		

[a] VICS indices are expressed as standard deviations above and below the mean for the 20 world leaders.
[b] Expected versus actual outcome for row player where 0 is upper-left, 1 is upper-right, 2 is lower-right, and 3 is lower-left quadrant of game matrix. Game solutions are in bold.
NOTE: Speeches: *n* = 6, world leaders: n = 20 from a variety of historical eras and geographical regions.
SOURCE: Adapted from Table 18.1 in Walker et al. (2003b), copyright 2003, courtesy of University of Michigan Press.

gic and tactical situation between Self and Other as a subjective game (Walker et al., 2011). Saddam Hussein's negative I-1 (−1.24) and negative P-4a (−3.80) valences for Self (Ego) plus his negative P-1 (−1.47) valence and positive P-4 (+3.80) valence for Other (Alter) specify his subjective strategic interaction game as characterized by a Bluff strategy for Self and a Bully strategy for Other.

These strategic orientations for Self and Other in his belief system make it likely that Saddam Hussein will define Other as an adversary rather than an ally, will pursue bluff tactics and increase them to punish, and will use bully tactics to dominate a weaker opponent unless met with firm resistance by an equal or stronger opponent (Schafer and Walker, 2006; Walker et al., 2011). Deterrent and compellent threats are unlikely to be effective unless made by a stronger adversary that has shown firm resolve to carry out the threat in the event of noncompliance. Then he will back down and retreat, as also predicted by Post's analysis, which documents historical examples of this pattern prior to the 1991 Iraq War (Walker et al., 2003b, pp. 389-390; see also Post, 2003b, pp. 341-342).

The outcome in Table E-2 for playing the bluff strategy assigned to Self and the bully strategy assigned to Other in the Iraqi leader's subjective game is (CO,CF) domination for Other (US) and submission for Self (IRQ), which Saddam found unacceptable. If US plays a deter/assure strategy instead of a bully strategy against Iraq's bluffing strategy, the outcome in Table E-2 is either (CO,CO) mutual cooperation or (CO,CF) submission by Iraq and domination by US. If the subjective game for Iraq is Bluff v. Bully and the subjective game for US is Deter versus Bluff and if each plays their own subjective game, then the outcome is always (CO,CO) mutual cooperation with one exception: if the game begins in the lower-right cell (CF,CF) deadlock and Iraq has the next move, then the final outcome is also (CF,CF) deadlock (Walker et al., 2011 Appendix, p. 289).

The examples of Saddam Hussein's personality traits, motivations, cognitive complexity, operational code beliefs, and subjective game illustrate how content analysis and leadership profiling can provide insights into the psychology of a peer/near-peer, regional, or non-state actor, which reflect a decision unit's definition of the situation, strategic orientation, and risk-taking propensity in a general, immediate, or extended deterrence situation. Employed with other methods of assessment, such as qualitative cognitive modeling, gaming, and simulations, the convergent validity of the results from any one of these methods can be tested by comparison with the results from the other methods.

There is an extensive store of information in the form of records from past gaming exercises and decision-making processes within those games, which may be re-analyzed with automated content analysis systems to retrieve the personality traits, motives, beliefs, and cognitive styles reflected in these texts attributed to participants in these games (Mintz et al., 1997; Young, 2001; Downes-Martin, 2013). They can reveal more precisely the personality biases at the individual level of the players, which may either reenforce or qualify the external validity of generalizations based on aggregation from individual to larger decision-making units.

Finally, there are also efforts to extend the models, methods, and tools for studying individual leaders to the examination of their social identities and roles in various group, organizational, and societal settings. Some analyses model the problem of studying larger units of analysis as the study of different forms of leader-advisor systems. They attempt explicitly to model the impact of a leader's personality on the decision-making dynamics of these systems (Leites, 1951; George, 1980; Winter, 2003b; Kowert, 2002; Hermann and Preston, 1994; Preston, 2001; Hermann, 2003a). The results of these studies in particular may provide the intellectual capital to eventually bridge the present gap between understanding the decisions of individual leaders and various kinds of group decisions in different cultural contexts.

For example, cultural norms and social identities may constrain leaders in recognizing and following the norms of arms control regimes such as the nuclear nonproliferation treaty (NPT). Therefore, it may be difficult for a general deterrence strategy to prevent proliferation of WMD even in the absence of the security threat posited by *Realpolitik* models as an incentive to acquire them. Cultural forces at work within societies and deeper, nationalist-based norms about what is legitimate and appropriate for countries that aspire to great power or regional power status may over-ride attempts to dissuade states from becoming members of the nuclear club.[7] France's creation of a nuclear *force de frappe* under De Gaulle is an example of these forces at work during the Cold War. Iranian aspirations for enhanced regional status in the post-Cold War era is another potential cause of proliferation, in which the outcome of the struggle in this case between going nuclear and limiting further proliferation is uncertain.

These possibilities also support the measurement and analysis of robust reasons and beliefs from historical case studies. It is possible with content analysis and leadership profiling tools to retrieve and model cultural drives and beliefs from real-world decision units as well as from the participants in laboratory gaming simulations and from the idealized decision units assumed by modeling efforts with game theory.

This step is necessary to assess the external validity of results from the hybrid application of abstract modeling and inductive gaming exercises. The external validity question associated with gaming, simulations, experiments, and math modeling efforts is whether the processes and outcomes created in the labora-

[7] The literature on norms and behavior is vast. A good discussion of a norms model, a security model, and a domestic/bureaucratic politics model applied to proliferation decisions is Sagan (1996-1997). An extension of this discussion with case studies of Iraq, China, Yugoslavia, and Argentina is contained in Hymans (2012). Discussions of the insights from models based on, respectively, social identities, status positions and belief systems are Hymans (2006), Larson and Shevchenko (2010), and O'Reilly (2012). A provocative treatment of the issues surrounding the creation and maintenance of international norms and nonproliferation regimes (nuclear, chemical, and biological) is in Joyner (2009). An excellent analysis of the motivations of small states to acquire WMD is in Preston (2007). An important comparative theoretical analysis of the operation of cultural norms in the international relations of different civilizations is contained in Lebow (2008).

tory simulations or math modeling exercises correspond to the behavior of actual decision-making units in the political world.[8]

CONCLUSION

Deterrence is at heart a psychological concept, resting on understanding the psychology of the deteree—for example, if the deteree is a non-state terrorist group seeking martyrdom, the threat of death will be taken as an incentive rather than a deterrent. Therefore, evaluation of proposals for deterrence and assurance must rest on a nuanced understanding of the mindset and decision-making of the adversary or ally whenever possible. In contrast to during the Cold War era, when the Soviet Union was the main source of a strategic threat to the United States, in the 21st century it is necessary to have an accurate understanding of the leadership styles and decision-making processes of a broad spectrum of dangerous adversaries and a proliferation of threats from very different sources. One can neither effectively and efficiently deter with a threat nor assure with a promise an adversary or ally that one does not understand.

The tools of content analysis and leadership profiling in conjunction with other methods and tools have the potential to meet the requirements of actor-specific knowledge for a strategy of tailored deterrence. An alliance of content analysis, leadership profiling, abstract modeling, gaming, and simulations as a suite of methods and tools is possible in order to solve the complex problems associated with studying the decision-making dynamics of single groups and multiple autonomous actors as decision units.

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[8] In a recent review, Downes-Martin (2013) concluded that war games, models and simulations in think tanks and planning cells used to plan strategic deterrence face two problems. The decisions predicted by participants for themselves and the leaders to be deterred are most likely inaccurate; decisions made or implied during precrisis war games are poor proxies for the decisions that will actually occur, even if the evolving situation is accurately predicted. However, cultural drives and, especially, beliefs are remarkably robust, even in the face of proven and credible contradictory evidence. Downes-Martin concludes that war games to address nuclear deterrence problems are more likely to provide credible results under the following conditions: (1) when the focus is on reasons for decisions made and predicted, not the decisions themselves; (2) the focus is on messages sent, and reasons for their (mis)interpretation; (3) the focus is on the beliefs of the players (planners) as well as the beliefs of the players; (4) the focus is on embedding these reasons into the models and simulations.

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U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment

A Workshop Summary

Norman M. Haller, Rapporteur

Committee on U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment: A Workshop

Air Force Studies Board

Division on Engineering and Physical Sciences

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Preface

Changes in the 21st century security environment require new analytic approaches to support strategic deterrence. Because current adversaries may be deterred from the use of nuclear weapons differently than were Cold War adversaries, the Air Force needs an analytic process and tools that can help determine those Air Force capabilities that will successfully deter or defeat these new nuclear-armed adversaries and assure U.S. allies. While some analytic tools are available, a coherent approach for their use in developing strategy and policy appears to be lacking. Without a coherent analytic approach that addresses the nuances of today's security environment, Air Force views of its strategic deterrence needs may not be understood or accepted by the appropriate decision makers. A coherent approach will support Air Force decisions about its strategic force priorities and needs, deter actual or potential adversaries, and assure U.S. allies.[1]

Strategic deterrence may now be far more difficult for the United States than during the Cold War. Compared to the Cold War bipolar, rational-actor model, new thinking is needed to cope with the complex notion of deterring other nuclear-armed or potentially nuclear-armed entities. As current nuclear non-peers become near-peers or peers, they may not act as expected. Non-peers that have or are developing nuclear weapons are often ruled by regimes that are difficult to penetrate, as well as regimes whose decision-making dynamics are difficult to interpret. Although these regimes may be considered irrational, other factors need to be taken into account, such as insular perspectives of adversaries; aberrant views of their role in their region; and historic, cultural, and religious biases, all of which affect the decision maker's cost-benefit calculus. U.S. security depends on having the right mix of strategic options and capabilities to deal with the new challenges. The United States may find itself engaged in a conventional war with such nuclear-armed adversaries. Some postulate that preventing escalation in such circumstances will be far more difficult than peacetime deterrence was during the Cold War. Adversaries may have powerful incentives to brandish or use nuclear weapons. It is conceivable that some nuclear-armed leaders who face very bad options may take desperate gambles, accepting a high probability of making things worse in exchange for a small hope of avoiding a large loss. Before ever getting to such a point, the Air Force must be able to understand fully and articulate convincingly its capabilities to contribute to deterrence.[2]

In this context, the Air Force in 2012 requested that the Air Force Studies Board of the National Research Council undertake a workshop to bring together national experts to discuss

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[1] Hunter Hustus, Technical Advisor, Office of the Deputy Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, "USAF A10 Perspective." White paper dated September 21, 2012.

[2] Ibid.

current challenges relating strategic deterrence and potential new tools and methods that the Air Force might leverage in its strategic deterrence mission. Titled "U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment," the workshop consisted of two 3-day sessions held in Washington, D.C., on September 26-28, 2012, and January 29-31, 2013.

The workshop committee was very pleased that the leaders of both Air Force organizations that championed this independent workshop, Lt Gen James Kowalski, Commander, Air Force Global Strike Command, and Maj Gen William Chambers, Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration, were available to discuss in detail their needs related to this important workshop. In addition, the committee was honored that Dr. C. Paul Robinson, president emeritus of Sandia National Laboratories, former ambassador, chief U.S. negotiator, and head of the U.S. delegation to nuclear testing talks with the Soviet Union, as well as Gen Larry Welch (USAF, Ret.), trustee emeritus and former president, Institute for Defense Analyses, and former Air Force chief of staff, were able to share their perspectives in two capstone talks. Also, the committee thanks the many expert speakers and guests who contributed immensely to both sessions of this workshop.

The workshop committee's role was limited primarily to planning and organizing the workshop sessions. The workshop committee was also provided opportunities to review drafts of the workshop summary for accuracy. As a function of planning for the workshop sessions, workshop committee members exchanged e-mails and read outside materials. Some workshop committee members were asked by National Research Council staff to give presentations and moderate workshop panels as individual workshop participants.

Gerald F. Perryman, Jr., *Chair*
Committee on U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment: A Workshop

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

John F. Ahearne, Sigma Xi, The Scientific Research Society,
Allison Astorino-Courtois, National Security Innovations, Inc.,
Arden L. Bement, Jr., Purdue University, and
Michael O. Wheeler, Institute for Defense Analyses.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views presented at the workshop, nor did they see the final draft of the workshop summary before its release. The review of this workshop summary was overseen by Robert J. Elder, Jr., George Mason University. Appointed by the NRC, he was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the author and the institution.

Contents

APPENDIXES

Acronyms

AFGSC	Air Force Global Strike Command
AFGSC/CC	Commander, Air Force Global Strike Command
DoD	Department of Defense
NATO	North Atlantic Treaty Organization
NRC	National Research Council
NSC	National Security Council
SAIC	Science Applications International Corporation
TIN	timed influence net
TOR	terms of reference
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USSTRATCOM	U.S. Strategic Command

1

Introduction

This report summarizes a two-part workshop titled "U.S. Air Force Strategic Deterrence Capabilities in the 21st Century Security Environment." The two workshop sessions were held in Washington, D.C., on September 26-28, 2012, and January 29-31, 2013, under the auspices of the Air Force Studies Board of the National Research Council. The workshop was attended by a very diverse set of participants with expertise in strategic deterrence and a range of analytic tools of potential interest to the Air Force. Specific terms of reference (TOR) for the workshop are listed in Box 1-1.

Early on, the workshop committee discussed the TOR, emphasizing that its work should produce something that can actually be used by the Air Force. More than once, committee members questioned whether the scope of this workshop should be limited to deterrence by "nuclear" forces or broadened to include deterrence by non-nuclear forces (e.g., conventional offensive weapons, missile defenses, cyber capabilities, space-based systems, and drones); the resulting discussion indicated that the workshop focus would be primarily on those tools and methods applicable to analysis of nuclear deterrence.[1] With respect to adjusting the TOR, the main concern was that "social network analysis and crowd sourcing" was explicitly called out, but it became clear that these terms were not meant to limit the techniques to be considered. After more discussion, the committee did not change the TOR but did develop several questions to be considered during the workshop, including the following:

1. How are the challenges for nuclear deterrence in the 21st century similar to and different from those of the 20th century?[2]
2. What are the analytic challenges, and what approaches are needed to resolve them?
3. What are the insights for the future and ancillary issues raised during workshop discussions that the Air Force should consider?

[1]Implications of cyberwarfare were not discussed extensively during the workshop.

[2]A participant noted that an additional issue was that the United States also knows more now, and if the 20th century were to be re-lived, deterrence strategy would be better. As of now, this question reflects the notion that the United States had it right in the 20th century, an interesting notion given two world wars, the Korean War, and the Vietnam War.

BOX 1-1
Terms of Reference

An ad hoc committee will plan and convene one workshop consisting of two 3-day meetings (separated for logistical reasons) to (1) examine integrated toolsets and methods, such as social network analysis and crowd sourcing, that provide insight into adversary decision calculi and insights into which Air Force capabilities are likely to be effective at influencing those decision calculi; and (2) develop terms of reference for an ad hoc study that would: (a) evaluate these integrated toolsets and insights on relevant Air Force capabilities and (b) analyze gaps.

The committee will develop the agenda for the workshop, select and invite speakers and discussants, and moderate the discussions.

In organizing the workshop, the committee might also consider additional topics close to and in line with those mentioned above. The meetings will use a mix of individual presentations, panels, breakout discussions, and question-and-answer sessions to develop an understanding of the relevant issues. Key stakeholders will be identified and invited to participate. One individually authored workshop summary document will be prepared by a designated rapporteur.[1,2]

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[1]This workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop. It is important to note that this rapporteur-authored workshop summary does not contain consensus findings and recommendations, which are only produced by National Research Council study committees.

[2]The terms of reference (TOR) for the workshop does not call for formal analysis and/or recommendations of how these analytic-based approaches might be used by the Air Force as part of its strategic deterrence mission; however, the notional TOR for a formal follow-on study, found in Chapter 5, does explicitly call for such analysis.

The first two questions align well with the panels and related discussions during the workshop, and the third question was explored as part of the dialog among the workshop participants at both sessions. Additionally, some speakers with a great deal of experience offered a variety of perspectives that helped establish a comprehensive backdrop for the workshop. Accordingly, the remainder of this report is organized as follows: Chapter 2, Various Perspectives; Chapter 3, Strategic Deterrence: Past, Current, and Future; Chapter 4, Analytic-Based and Non-Traditional Approaches; and Chapter 5, Insights for the Future. Finally, as a result of this workshop, the Air Force possesses a rich variety of independent thoughts regarding potential analytic approaches to substantiate Air Force concepts and articulate Air Force capabilities as deterrence strategy is developed in the 21st century security environment. The Air Force will also have illustrative elements of a TOR for a future longer-term study to evaluate potential toolsets and analyze gaps (see Chapter 5).

2

Various Perspectives

AIR FORCE PRESENTATIONS

Maj Gen William Chambers, assistant chief of staff of the Air Force for strategic deterrence and nuclear integration, Headquarters U. S. Air Force, started both workshop sessions. He observed that deterrence is not just an Air Force issue; it is a national issue. As shown in Figure 2-1, Gen Chambers emphasized that (1) the strategic deterrence challenge is different now than decades earlier, (2) for the 21st century multi-nodal world, one type of deterrence does not fit all anticipated needs, (3) ensuring stability is the preeminent goal,[1] and (4) the Air Force needs analytical tools to help it address the looming deterrence challenges.[2] These challenges, he stated, include pressures to reduce future U.S. nuclear arsenals while maintaining strategic stability as well as regional assurance in the face of actual and potential proliferation of nuclear weapons by rogue states. Gen Chambers emphasized the need to recapitalize and modernize every aspect of the nuclear deterrent, specifically calling attention to the two Air Force components of the triad (land-based missiles and bombers).[3] He also stressed a message that was revisited numerous times during the workshop—*less is different, things change as nuclear forces are reduced.* In the new strategic environment, he indicated, a new continuum of nuclear and conventional forces might become more likely. In all of this, he indicated, the Air Force needs to identify the methodologies that could provide a sound analytic basis on which to establish the Air Force strategic force requirements and priorities and justify its plans.

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[1]During Gen Chambers' presentation, a participant posed a question about stability: "Does the other side always want stability?" This question elicited considerable discussion among the workshop participants. Gen Chambers agreed that some adversaries may actually want to foment instability.

[2]*Strategic deterrence* is described in this workshop summary as a complex-coupled problem involving many contextual factors of technical, social, political, and economic importance. These are often classified as "wicked problems" for which credible predictions (the needs for which are emphasized in several parts of this report) are unlikely. Projections based on trends, analytical insights, and measured time steps may be the best that can be expected. While barriers to predictions are not discussed in this workshop summary, the need to estimate uncertainties and error bands over time by rigorous analyses was a theme raised throughout the workshop. It may be that such analyses will require a combination of heuristics, which is also a point raised during the discussions associated with Peter Todd's presentation, "Heuristics in Uncertain Environments: Ecological Rationality," found in Chapter 2.

[3]The third element of the triad consists of submarine-based ballistic missiles.

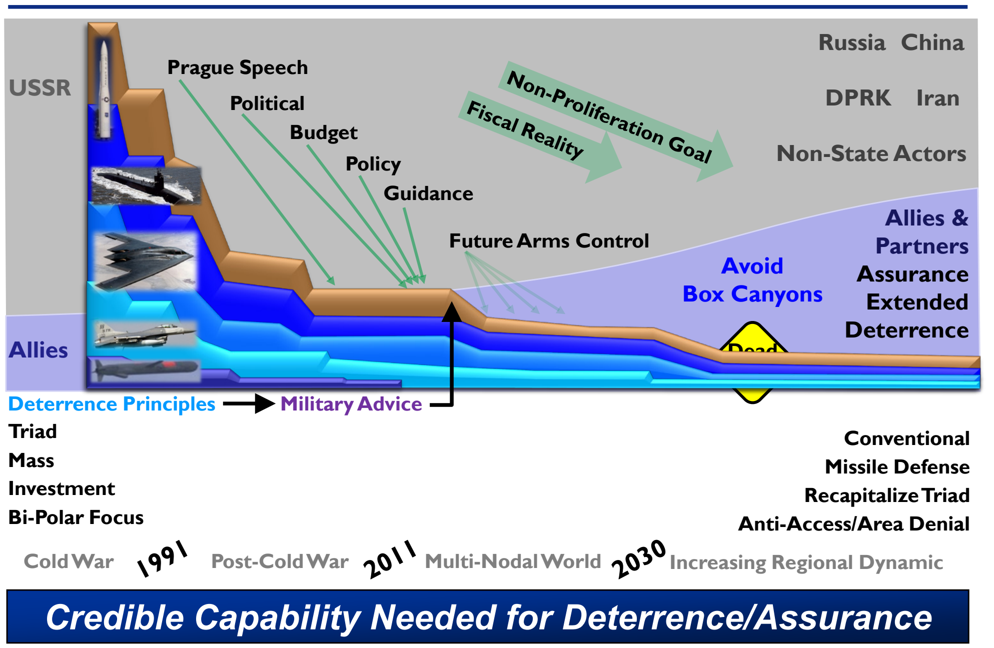

FIGURE 2-1 Ensuring that stability is the outcome. SOURCE: Maj Gen William Chambers, Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, “A10 Opening Remarks,” presentation to the workshop on September 26, 2012.

Near the ends of both workshop sessions, Gen Chambers provided expanded discussions of his needs. A synopsis follows: Given the actors of the future, he questioned what analytical tools can be used. Current analyses, such as analyses supporting the nuclear triad, may no longer be sufficiently persuasive. He was heartened to see the intellectual capabilities being applied to this multi-disciplinary problem. Observing that regional issues are compelling, Gen Chambers noted that being able to handle the regional problem sets with analytical tools is important, so, if this workshop or any follow-on study leads to production of analyses that will help the Air Force make sound arguments for the appropriate regional flexibility, the efforts will be a success.[4] He added that it is all about investing in the right systems for the future.

Lt Gen James Kowalski, commander, Air Force Global Strike Command, emphasized in his presentation at the first workshop session that the United States is no longer in a Cold-War setting; rather, the issue is how to get from there to today and beyond, especially given the multi-polar backdrop that now exists. As shown in Figure 2-2, Gen Kowalski indicated that nuclear deterrence is the cornerstone of strategic stability (among the great powers, no one has incentive for a first strike) and underpins U.S. conventional and diplomatic power. He expressed concern about safety, security, and effectiveness of U.S. nuclear forces in light of the possibility of moving to lower numbers of nuclear weapons, for example, a few hundred deliverable warheads along with diminished capabilities provided by national laboratories and the industrial base.

[4]While not stated explicitly by Gen Chambers, an important extension of this point is the need to identify the viable alternatives for solving the problem backed up by rigorous analyses of the advantages and disadvantages of each alternative. The selection among the alternatives should be left to the decision maker.

- **Nuclear Deterrence is the cornerstone of strategic stability**
  - **Framework for mil-to-mil and diplomatic engagement**
  - **US nuclear forces are part of a regional deterrence architecture**
  - **Nuclear assurance reduces allies' incentives to seek their own nuclear weapons**
- **Conventional capabilities prepared to defeat adversaries and succeed in a wide-range of contingencies**
  - **Long range power projection capabilities deter adversaries**
  - **Reinforces the integrity of alliances and security partnerships**
  - **Flexibility in a complex, multi-polar geopolitical environment**

Nuclear deterrence underpins our nation's conventional & diplomatic power

UNCLASSIFIED ***To Deter and Assure***

FIGURE 2-2 Air Force Global Strike Command's bottom-line mission. SOURCE: Lt Gen James Kowalski, "AFGSC Science and Technology Challenges to AFSB," presentation to the workshop on September 26, 2012.

Mr. Hunter Hustus, technical advisor, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, provided a presentation to the first workshop session titled "Where Are We Now? What Is Useful?" An abstract of Mr. Hustus' presentation is found in Box 2-1.

BOX 2-1
Where Are We Now? What Is Useful?
Hunter Hustus, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration

The emergence of new nuclear weapons states erodes the Cold War bi-polar nature of strategic deterrence. Reductions in the size of U.S. and Russian nuclear weapons arsenals bring an end to the condition of Mutually Assured Destruction. As arsenal size decreases, the value of each warhead/system increases as does the complexity of the deterrence challenge. Policies on force structure, targeting, missile defenses, arms control agreements, and social/economic organization require new analysis. Cold War foundational constructs and analytic approaches (e.g., game theoretic) for strategic deterrence remain informative and necessary but may be insufficient for full comprehension of modern deterrence dynamics. The Air Force looks forward to the results of the workshop.

ADDITIONAL PRESENTATIONS

Dr. Daryl Press, associate professor of government, Dartmouth College, discussed future nuclear challenges at the first workshop session. The key takeaways from his presentation were (1) nuclear deterrence may be more difficult than most believe; (2) the biggest challenge is avoiding escalation during wars; and (3) there are analytic challenges regarding the future of the U.S. nuclear arsenal. Dr. Press likened today's escalation problem to the North Atlantic Treaty Organization's (NATO's) problem during the Cold War—when NATO faced what was believed to be overwhelming Soviet conventional power, and so nuclear weapons were likely to be used to stop a Soviet advance. Today the United States enjoys conventional superiority, but the roles are reversed, and less capable entities now possess nuclear weapons. In other words, adversaries may have a powerful incentive to "go nuclear," because losing a war to the United States can lead to a very bad outcome. Dr. Press closed by questioning if there is an emerging U.S. nuclear capability problem—for example, high versus low yields—and suggesting analytic-approach implications for a follow-on study to this workshop (i.e., perceptions and deterrence or capabilities and deterrence).

Lt Gen Frank Klotz (USAF, Ret.), senior fellow for strategic studies and arms control, Council on Foreign Relations, offered his insights at the second workshop session. An abstract of Gen Klotz's remarks is found in Box 2-2.

Mr. David Palkki, deputy director, Conflict Records Research Center, National Defense University, provided a presentation to the first workshop session titled "Saddam Hussein's Views on the Role of Nuclear Weapons and Perceptions Influencing his Decision-making." An abstract of Dr. Palkki's presentation is found in Box 2-3.

Dr. Peter Todd, professor of cognitive science, informatics, and psychological and brain sciences, Indiana University, provided a presentation to the second workshop session titled "Heuristics in Uncertain Environments: Ecological Rationality." An abstract of Dr. Todd's presentation is found in Box 2-4.

BOX 2-2

Achieving a Politically and Technically Sustainable Nuclear Posture for the 21st Century

Lt Gen Frank Klotz (USAF, Ret.), Council on Foreign Relations

The 2010 Nuclear Posture Review states that as long as nuclear weapons exist, the United States will sustain safe, secure, and effective nuclear forces. Other nuclear-armed states show little inclination to reduce their stockpiles to zero; some are even pursuing substantial efforts to modernize, diversify, and, in some cases, expand their existing nuclear forces. At the same time, public interest and political support for programs to maintain, much less modernize remaining U.S. nuclear capabilities have sharply declined since the end of the Cold War. Achieving consensus on the way ahead requires that two different, but not necessarily mutually exclusive beliefs be taken into account: (1) that appropriately sized nuclear forces still play an essential role in protecting U.S. and allied interests, and (2) that the United States must lead international efforts to limit and reduce nuclear arsenals, prevent proliferation, and secure nuclear materials.

BOX 2-3
Saddam Hussein's Views on the Role of Nuclear Weapons and Perceptions Influencing His Decision Making
Mr. David Palkki, National Defense University

When U.S. and U.S.-allied troops entered Iraq in 2003, they captured millions of pages of Iraqi documents and several thousand audio files of Saddam Hussein's meetings with his inner circle. These records provide unparalleled material with which to assess a recent adversary's perceptions and decision making. I present two major findings regarding Saddam's beliefs about nuclear weapons. First, Saddam and other Iraqi leaders believed that nuclear weapons provide strategic leverage, and they pursued nuclear weapons, in part, to enable conventional aggression. Iraqi acquisition of nuclear weapons would have led to violent, destabilizing Iraqi behavior. Analysts have paid too little attention to offensive, revisionist motives driving Saddam and other leaders to pursue the bomb. Second, concerns about U.S. nuclear retaliation were central to Saddam's decision not to use chemical or biological weapons in 1991. Contrary to most accounts, however, neither ambiguous U.S. nuclear threats nor U.S. threats to replace the Ba'athist regime led to Saddam's restraint.

BOX 2-4
Heuristics in Uncertain Environments: Ecological Rationality
Dr. Peter Todd, Indiana University

Traditional views of rational decision making assume that individuals should make choices by using powerful mechanisms to process all of the information available. But given that human and animal minds have evolved to be quick and just "good enough" in environments where information is often costly and difficult to obtain, we should instead expect individuals to draw on an "adaptive toolbox" of simple, fast and frugal heuristics that make good decisions with limited information and processing. These heuristics typically ignore most of the available information and rely on only a few important cues. And yet they make choices that are not only accurate when fitting their appropriate application domains, but can also be *more* accurate than traditionally rational strategies in uncertain environments—that is, when they have to generalize to new situations. Simple heuristics yield *ecological rationality* through their fit to particular information structures in the environment, and achieve their robustness in the face of environmental uncertainty via stopping rules that limit the cues they consider and so avoid overfitting noise—that is, assigning too much weight to useless cues. They also lessen the cost and other risks of gathering information. People successfully employ a variety of these heuristics in particular decision situations, such as those with time pressure and without the need to justify actions, for tasks including choosing among currently available alternatives and searching for a good-enough option out of a sequence of possibilities seen over time.

One of the discussion points after Dr. Todd's presentation concerned the availability and use of information about the types of heuristics that different leader personalities might use.

Ms. Amy Woolf, specialist in nuclear weapons policy, Congressional Research Service, shared her views on the evolution of U.S. strategic deterrence at the second workshop session. Ms. Woolf described the process of supporting Congress—a body that consists of more than 500 elected officials and thousands of staff representing interests of all the states of our nation and numerous districts within those states—a body in which most members are interested in matters other than strategic deterrence. Ms. Woolf offered that it has been useful that a small, focused group of individuals in Congress have remained interested in and committed to nuclear matters and that credible analysis could potentially be used with great effect on this group. Finally, Ms. Woolf emphasized that tightening budgets will affect congressional decisions going forward.

3

Strategic Deterrence: Past, Current, and Future

PANEL ON DETERRENCE CONCEPT UPDATES AND APPROACHES

Dr. Michael Wheeler, senior research staff, Institute for Defense Analyses, led the panel titled “Deterrence Concept Updates and Approaches” at the first workshop session. He began by describing what has and has not changed since the Cold-War (see Box 3-1). Dr. Wheeler was followed by Mr. Orde Kittre, who discussed the sanctions regime against Iran. He believes that few U.S. allies are convinced that the United States will use force against Iran over its nuclear weapons program, and he indicated that Iran's use of a nuclear weapon might be non-deterrable should it succeed in developing one. Even if Iran does not use a nuclear weapon, a nuclear-armed Iran could become emboldened. Further, he stated that several neighboring states could then also want to acquire nuclear weapons. He noted that sanctions worked in Libya, and more recent sanctions on Iran appear to be having an effect; its foreign exchange reserves are key.

Mr. Patrick McKenna, chief, Plans Evaluation and Research Division, U.S. Strategic Command (USSTRATCOM), next discussed deterrence operations and concepts of joint operations, including the official Joint Operating Concept document (which is unclassified and can be downloaded).[1] At the document's core are recognition of the changed international environment and the need to continue to deter—for example, to deter North Korea’s use of a nuclear weapon in conflict. Mr. McKenna indicated that deterrence in this case means decisively influencing an adversary's decision making, which covers not only the final decision maker, but others on whom that person or small group relies in making decisions. In general, Mr. McKenna noted, the point is to deter adversary X during condition Y from doing Z, and Z could include not only nuclear-related behavior but activities in space, cyber, and proliferation, among other domains. He stated that adversary decision calculi are based on a profile. All of this is applicable to this workshop because different analytical tools might be needed for his organization's purposes—for example, understanding how an adversary might perceive use of a particular weapon, such as a high- versus low-yield nuclear weapon (e.g., bomber versus missile).

Finally, Dr. Elbridge Colby, a research analyst, provided a brief set of remarks titled “Extended Deterrence.” An abstract of Dr. Colby’s remarks is given in Box 3-2.

[1] Mr. McKenna returned for the second workshop session, at which time he discussed underlying analyses for the U.S. strategic force structure; his second presentation is summarized in Chapter 4.

BOX 3-1
Deterrence: What Has and Has Not Changed
Dr. Michael Wheeler, Institute for Defense Analyses

What Has Not Changed

1. The importance of being able to retaliate with nuclear weapons if attacked with nuclear weapons. Bernard Brodie emphasized this in his classic studies at the start of the nuclear age, as did senior Air Force leaders in the 1946 study (since unclassified) led by Generals Spaatz, Vandenberg, and Norstad.

2. Nuclear weapons are uniquely lethal and can threaten societal existence. The loss of even one city would be devastating; debates took place during the Cold War about how much damage a society could suffer before it would collapse. This was discussed in the 1950 American security review (NSC-68) led by Paul Nitze (who then was head of the Policy Planning Staff in the State Department), and in the 1950s British study by the Joint Inter-service Group for the Study of All Out War.

3. Nuclear weapons are different. A nation can lose a conventional war and recover politically, while nuclear weapons imply otherwise. North Korea has been able to threaten turning Seoul into a sea of glass for decades, but look at the intensity of diplomacy now that it has nuclear weapons. Also, look at the massive response that would be expected if a nuclear bomb ever is discovered being smuggled into a country (compared to the responses for other weapons smuggling).

4. The realities of domestic and bureaucratic politics have not changed: interagency bickering, key players being cut out, and the like. There are many examples where regional experts were excluded. For example, the Russian experts George Kennan and Chip Bohlen were kept out of the NSC-68 project (with whose conclusions they disagreed), as was Marshall Shulman (the State Department's Soviet expert during the Carter administration) during the studies leading up to Presidential Directive 59.

5. The broad outlines of the nuclear infrastructure and posture have not changed; for example, we still have three national laboratories and a triad of strategic forces.

6. Many legacies remain. For example, Russia still has the largest arsenal. Also, alliances such as NATO still rely upon the American extended deterrent.

What Has Evolved

1. Extended deterrence.

2. Proliferation challenges.

3. Arms control (e.g., the Strategic Arms Reduction Talks process, the Non-Proliferation Treaty).

What Has Changed

1. The fiscal environment and industrial base in the United States has contracted, while that in China has expanded.

2. N-party nuclear interactions are more common, as are regional interactions not directly involving the United States (as in South Asia).

Box 3-1, *continued*

3. The ubiquitous nature of the information technology revolution (database available for profiling, transparency and monitoring).
4. "Forces to the President of the United States" (nuclear, but also others: Title 10/Title 50 interactions in cyber; drone strikes; special operations raid into Pakistan to go after Osama Bin Laden).
5. No more nuclear testing/different approach to production/decline of expertise.
6. Rise of China.

Planning/Methodologies

1. U.S. Strategic Command now is the only analytic center (once had many).
2. 1960s when techniques adopted in the Department of Defense.

BOX 3-2
Extended Deterrence
Dr. Elbridge Colby, Research Analyst

Effective extended deterrence derives from a potential adversary's perception that the state extending deterrence has both the capability and the resolve to use force—possibly and perhaps necessarily including nuclear weapons—in a manner sufficiently detrimental to the potential aggressor's interests to outweigh any benefits such aggression would entail. The two key factors in effective extended deterrence are capability and resolve. Capability, in turn, can be broken down into the ability to deter through denial or through infliction of cost, with the former being more challenging. Resolve is made harder when an opponent has nuclear weapons of his own, and is especially challenging in extended deterrence because it involves the threat to use nuclear weapons for an ally's benefit by putting one's self at risk. This problem was perhaps the central one of the Cold War. While it is less central today, it remains important and may become more so. This is for two reasons: first, the United States continues to extend deterrence to over 30 countries, including a number possibly threatened by nuclear-armed adversaries; second, the U.S. conventional ascendancy of recent years appears to be narrowing; and, third, nuclear weapons appear to be proliferating to more states. The Department of Defense and the U.S. Air Force therefore need to think about what strategic deterrence capabilities are going to be required for these extended deterrence challenges.

Many workshop participants had comments and questions after the panel discussion. A synopsis follows. Mr. Kittre noted that "lawfare" is the idea that laws may be used as a tool to achieve what used to be done by military means, but there are constraints to laws (e.g., serious problems with China where the United States cannot deter cyber activity or proliferation support to other nations). There was an exchange of ideas on (1) extended deterrence (look at the costs and benefits of honoring commitments versus not honoring them) and (2) if there is an increase or decrease in an entity's caution after acquiring nuclear weapons. A workshop participant argued that there are implications to the U.S. force structure if it goes to very low numbers (e.g., to counter value instead of counter force). But Mr. McKenna indicated that strategy comes first: Would pure, city-busting force look different; and regarding timing, can it be done in 30 minutes or several weeks? However, if counter force, it likely cannot be done at lower numbers unless, perhaps, both sides go down. (A participant commented that one could also go after the other side's conventional forces.) A participant indicated that Iran is concerned that the United States wants regime change (look at what happened in Libya), and the United States tacitly accepts Pakistan and North Korean nuclear weapons, so why not a nuclear Iran eventually? A question was also raised about how one demonstrates a credible threat (e.g., B-52s, very large conventional ordnance). A participant commented that the United States is a tremendously unpredictable country, and, if provoked, it can be very decisive.

TAILORED DETERRENCE

Dr. Barry Schneider, retired director, U.S. Air Force Counterproliferation Center, provided a presentation to the first workshop session titled “Tailored Deterrence.” An abstract of Dr. Schneider’s presentation is found in Box 3-3.

Dr. Jerrold Post, professor of psychiatry, political psychology, and international affairs and director of the Political Psychology Program, George Washington University, provided a presentation to the first workshop session titled “Actor-Specific Behavioral Models of Adversaries: A Key Requirement for Tailored Deterrence.” An abstract of Dr. Post’s presentation is found in Box 3-4.

BOX 3-3
Tailored Deterrence
Dr. Barry Schneider, U.S. Air Force Counterproliferation Center (retired)

Deterrence must be tailored to (1) specific adversary leaders, (2) in specific scenarios, (3) utilizing a range of verbal and non-verbal communications, and (4) cognizant of the balance of military, economic and political power between the parties. To understand the adversary leadership, it is important to research their personality profiles, decision-making roles, propensity toward risk taking, decision processes, and their views of the U.S. leaders and credibility of U.S. deterrent threats. Where there is one dominant decision maker as there was with Saddam Hussein and Iraq, it is most important to understand that leader’s personality and personal history. Where power is shared among elite, understanding and predicting is harder. However, we must try to understand how adversaries weigh costs and benefits of possible courses of action in a given set of scenarios. Further, we must discern how power is distributed within a given adversary regime, the presence of factions on different types of decisions, and their standard operating procedures, military doctrine and strategies. In addition, it is useful to know the cronies that surround top leaders and what motivates them as well as the regime’s key assets and critical infrastructures and the regime’s key support elements.

BOX 3-4
Actor-Specific Behavioral Models of Adversaries: A Key Requirement for Tailored Deterrence
Dr. Jerrold Post, George Washington University

One cannot extrapolate uncritically from deterrence doctrine developed during the Cold War to the post-Cold War era. Conflicts now can be precipitated by rogue leaders of outlaw nations, many of whom possess or seek to possess weapons of mass destruction. There is now no "one size fits all" in terms of deterrence, but rather the need for tailored deterrence based on actor-specific behavioral models. The profile of Saddam Hussein, offered in testimony before the House of Representatives, is presented to illustrate how a nuanced political personality profile can inform policy decisions. The profiles of three leaders of current concern are then offered: Mahmoud Ahmadinejad from Iran, the Kim Dynasty in North Korea, and Bashar al-Assad of Syria. What deters one leader may provoke another. This emphasizes the importance of an intelligence effort and analytic capabilities to develop such nuanced profiles.

CAPSTONE PRESENTATIONS

Dr. C. Paul Robinson, president emeritus, Sandia National Laboratories, provided capstone remarks at the first workshop session titled "Future Strategic Deterrence and National Security Challenges for the United States." An abstract of Dr. Robinson's remarks are found in Box 3-5. In responding to questions, Dr. Robinson provided other perspectives, such as (1) situation awareness should never be undervalued; (2) deterrence at the strategic level must rely on overwhelming fear; (3) the United States must tailor to deal with North Korea, Iran, etc., and (4) there are not enough dollars to produce the intelligence, surveillance, and reconnaissance everyone wants. Although the U.S. government must accept that there are things it will not know—it will probably know enough to communicate what is held at risk and be able to generate fear.

Gen Larry Welch (USAF, Ret.), trustee emeritus and former president, Institute for Defense Analyses, provided capstone remarks at the second workshop session titled "21st Century Deterrence." An abstract of Gen Welch's remarks are found in Box 3-6.

Gen Welch's responses to questions produced more perspectives, such as: (1) the United States should assume others are acting in what they believe are their own national interests, so it is important to understand their cultures and what their leaders believe about their true national interests; (2) the Department of Defense also needs tools to give U.S. decision makers broad understanding of what is occurring in various places; and (3) when contemplating lower levels of nuclear weapons, confidence in extended deterrence should not be lost.

BOX 3-5
Future Strategic Deterrence and National Security Challenges for the United States
Dr. C. Paul Robinson, Sandia National Laboratories (emeritus)

During the Cold War, the realization came that strategic deterrence just might be the most successful means of preventing major wars. The long peace that has extended from 1945, when nuclear weapons brought an end to the worst world war in history, continues today. The most important question for us to address is "How can we ensure that deterrence through fears of retaliation with nuclear weapons can continue ***in perpetuity*** to prevent war? This talk suggests that ***deterrence is always an active and dynamic process***, and that we must focus on the inputs to the process, if we expect the great outputs it can provide. After reviewing the history of deterrence, as seen by both Cold War protagonists, and the work carried out within the United States, one can conclude that today —with rapid changes in the world— the tasks are more complicated. We seem to be doing less well in anticipating and changing the U.S. deterrent to ensure it will remain effective for a future "multilateral nuclear-armed world." Examples discussed include: tailoring our deterrent plans for particular nations and leaders, examining changes in the target base—e.g., few if any missile fields left, more buried targets, many more mobile missiles (on underground highways?), deeply buried targets; and the characteristics of our delivery systems no longer match the targets (e.g., the low spatial density of targets obsoletes MIRVed systems, the high yields of Cold War systems no longer fit to deter less-than-major nations). The recent Air Force decision for an updated cruise missile was praised as being the likely weapon-of-choice for multilateral deterrence of less-than-major nations. The bottom line called for renewed attention to tailor the U.S. strategic deterrent to today's world.

BOX 3-6
21st Century Deterrence
Gen Larry Welch (USAF, Ret.), Institute for Defense Analyses (emeritus)

The Cold War strategic nuclear deterrence model requires expansion and adaptation to be relevant to the broader set of 21st century deterrence challenges. Still, the basic principles continue to have wide application. Further, the central Cold War nuclear deterrence task will remain relevant so long as there is the capability to destroy the United States as we know it in the hands of a government that is yet to become a reliable trustworthy friend. The most basic principle of deterrence is the need to instill in the minds of potential adversaries that the potential cost and risk of an action inimical to our interests or those of our allies far exceeds the potential gain. We were confident that we could meet that need in dealing with the leaders of the Soviet Union because we expended enormous effort over a period of decades to understand their motivations and what they valued. For deterrence to be effective on a wider scale in the 21st century, we will need to greatly increase our focus on understanding the motivations and values of a far wider and more complex set of national and trans-national actors. That understanding is essential to fashioning effective deterrent policies, strategies, and capabilities.

4

Analytic-Based and Non-Traditional Approaches

ANALYTIC-BASED APPROACHES

Dr. Paul Davis, principal researcher, Pardee Graduate School, RAND Corporation, led the panel titled “Analytic-based Approaches for Deterrence Analysis” at the first workshop session. He began by discussing some lessons learned from past work, including the following: (1) study deterrence with relatively simple models; (2) the paradigm of “rational actors” is not viable; and (3) use alternative models to defeat tyranny of best estimate since our best-estimate guesses of utility functions for the other side are not that useful and “history is replete with us getting it wrong.” Dr. Davis believes much of past deterrence work has been driven by theory, and new methods can be brought to bear to inform revised theory, such as evidence from case studies, crowd-sourcing to uncover factors and mindsets, the man-machine search of data for patterns, and “historical-statistical empirical analysis.” Dr. Davis added that newly developed factor-tree methods (qualitative modeling) are also quite useful in thinking about deterrence and other issues. Similarly, he noted that simple models, describable in a few viewgraphs, can frame potential adversary reasoning to help inform U.S. strategy. This can be called, with an admittedly pretentious label, synthetic cognitive modeling because it can be actor specific and highlight what the adversary worries about and has to balance.

Dr. Rob Axtell, chair, Department of Computational Social Science, Krasnow Institue for Advanced Study, George Mason University, followed with a presentation titled “Robustness and Resilience of Models Involving Social Agents.” An abstract of Dr. Axtell’s presentation is provided in Box 4-1.

Dr. Rita Parhad, associate partner, Monitor360, then addressed elicitation of subject-matter experts and crowd-sourcing. To illustrate the point about whether an adversary does or does not want stability, she raised a series of questions like (1) how can we tailor deterrence in that situation; (2) what can we learn from the adversary's response to our actions, messages, and policies; and (3) how can we “profile” adversaries with complex, factionalized, or opaque decision making? For deterrence to be effective she believes the socio-cultural context, along with associated motivations and actions, needs to be understood and elicitation of subject-matter experts and crowd-sourcing offer analytic techniques to gather non-U.S. perspectives and insights. Typical products of that analytical process include (1) master narratives, such as mindsets and beliefs for a country; (2) analyses of the future, such as persistent and forward-

BOX 4-1
Robustness and Resilience of Models Involving Social Agents
Dr. Rob Axtell, George Mason University

We are experiencing a revolution in the social sciences as conventional conceptions of human behavior—rationality, well-mixedness, equilibrium—are replaced by (1) the behavioral revolution in which experiments are used to elicit human behavior in specific environments, and (2) the computational revolution, in which we can scale up from the 10-25 subjects typical in the laboratory to tens of thousands or even millions of agents. Individual agent-based computational experiments in such environments can point out brittleness of policies based on optimization calculi. Systematic exploration of policy spaces can lead to more robust and resilient policies than can be predicted or achieved by other means. In order to accomplish this research program, significant resources need to be dedicated to understanding behavior in relevant domains. Specifically, regarding deterrence, signatures of sudden changes in societal behavior are not well understood, with conflicting hypotheses being advanced—e.g., some researchers claim that loss of diversity brings on rapid change while others argue that rapid growth of diversity signals abrupt transitions. An extended example from finance was indicated as a harbinger of things to come across the social sciences.

looking critical questions for a country; and (3) key influencers, such as understanding who matters in a country and how they might act, all of which could be helpful for deterrence by providing a critical context in which to make decisions.

Dr. Rafael Alonso, vice president and division manager, Autonomy and Analytics Division, Science Applications International Corporation (SAIC), finished the panel presentations by focusing on social network analysis. He indicated that most current deterrence tools do not work all that well in the context of state actors leveraging non-state actors, including terrorists. If a state is using a terrorist network, deterrence becomes very hard. He noted that it is difficult to understand the power relationships in those kinds of social networks, and the networks are seldom complete and change a lot. Mining the financial and communications data of such networks has been effective, however. He described some improvements that are underway, such as enriching text data with video or imagery and better analyzing power relationships in social networks. Dr. Alonso also touched on crowd-sourcing, suggesting its intuitive appeal due to the “safety” of large numbers may be illusory because—for example, of uninformed opinions and possible group-think—the desired result is not the same as dividing the group result by the number of individuals in the group (N).

Some key comments from various workshop participants followed. For example, all three techniques offer a framework. There is potentially useful information in these methods. After a U.S. announcement, one could sweep through responses—for example, in a country's media to suggest how the announcement was received. A participant posited sentiment mining as a tool for how to gauge what a whole population is thinking. A participant argued that these tools are more art than science. Another participant questioned how these tools could be used for deterrence. There was a suggestion that agent-based modeling captures complex behaviors, so, in principal, it can be used to see the behaviors of N states interacting. Crowd-sourcing [which refers to learning from experts and is not the same as social media or sentiment mining from a broad population], according to another participant, could be useful where leadership is centralized but cares about how the people feel (e.g., China). Another view was that for crowd-sourcing to be viable, one must get subject-matter experts engaged from day one. Crowd-sourcing is potentially useful, not just for what deters but for what can reassure allies. Several participants agreed that these tools are good for expanding knowledge of possible outcomes and allow for greater numbers of actors and interactions.

During the second workshop session, two speakers explained the analytical techniques their organizations employ for strategic forces. These presentations, summarized below, covered in more detail some of the information discussed at the first workshop session.

Mr. Patrick McKenna, chief, Plans Evaluation and Research Division, U.S. Strategic Command (USSTRATCOM), provided an overview of the analytic methodology used by USSTRATCOM to develop the desired strategic force structure and associated capabilities. He emphasized that strategy (against the backdrop of world environment) drives the force requirements. Strategy is followed by desired ends and *ways* and *means* of achieving the ends. He provided an illustrative strategic end, *deter aggression against the United States and its allies and maintain stability.* One of several effective *ways* to do that might be *demonstrate credible capability to hold at risk values or capabilities or assets an adversary values highly.* Mr. McKenna stated that one of several assessment metrics for that way could be *difference between U.S. and adversary force size in terms of prompt, survivable weapons;* this metric would then be used as part of the overall analysis of, for example, required U.S. counterforce capability (numbers and types of missiles and bombers)—the *means*. In response to a question about bringing metrics into a political debate, Mr. McKenna said his organization provides quantitative indicators with a qualitative summary, but he thought they could do better, and he challenged the workshop participants to help.

Maj Justin Sorice, scientific analyst, Air Force Office of Studies and Analyses, Assessments, and Lessons Learned, provided a presentation titled "A Framework for Strategic Deterrence Analysis." An abstract of Maj Sorice's presentation is found in Box 4-2.

BOX 4-2
A Framework for Strategic Deterrence Analysis
Maj Justin Sorice, Air Force Office of Studies and Analyses, Assessments, and Lessons Learned

An analytical framework is required to examine the interdependencies of strategies, capabilities and partnerships given planned as well as potential future reductions in the role and number of United States nuclear weapons. This presentation will examine how such a framework can be used to allow the U.S. military to think about studying strategic deterrence in the 21st century security environment, what factors and initial assumptions are required, and what conclusions are derived from the proposed framework.

NON-TRADITIONAL ANALYTIC APPROACHES

Dr. Allison Astorino-Courtois, executive vice president, National Security Innovations, Inc., set the stage by leading a panel titled "Non-Traditional Approaches to Deterrence" at the first workshop session. "How does all this relate to deterrence?" she asked rhetorically and answered, "We do not know." She acknowledged the complex relationships, multi-actor scenarios, and nth-order effects of the 21st century and introduced a suggested set of organizing columns, as shown in Figure 4-1, which could help characterize the tools, approaches, and methods.

For example, analysis of social networks and leader profiling could be selected from a long list of possible tools (column 1) to be used to help characterize a threat (one choice from many possible purposes in column 2) in one of several domains (nuclear, non-nuclear in column 3) under conditions of peace or conflict (column 4). She noted that this organization demonstrates the broad net of conditions under which these tools might be applicable. In other words, the question must be known before the right tools can be employed.

CAPT Gail Kulisch (USCG, Ret.), Kiernan Group Holdings, provided a presentation titled "The Crafty Bastard Innovation Cycle and Solution Creation Methodology."[1] An abstract of CAPT Kulisch's presentation is found in Box 4-3.

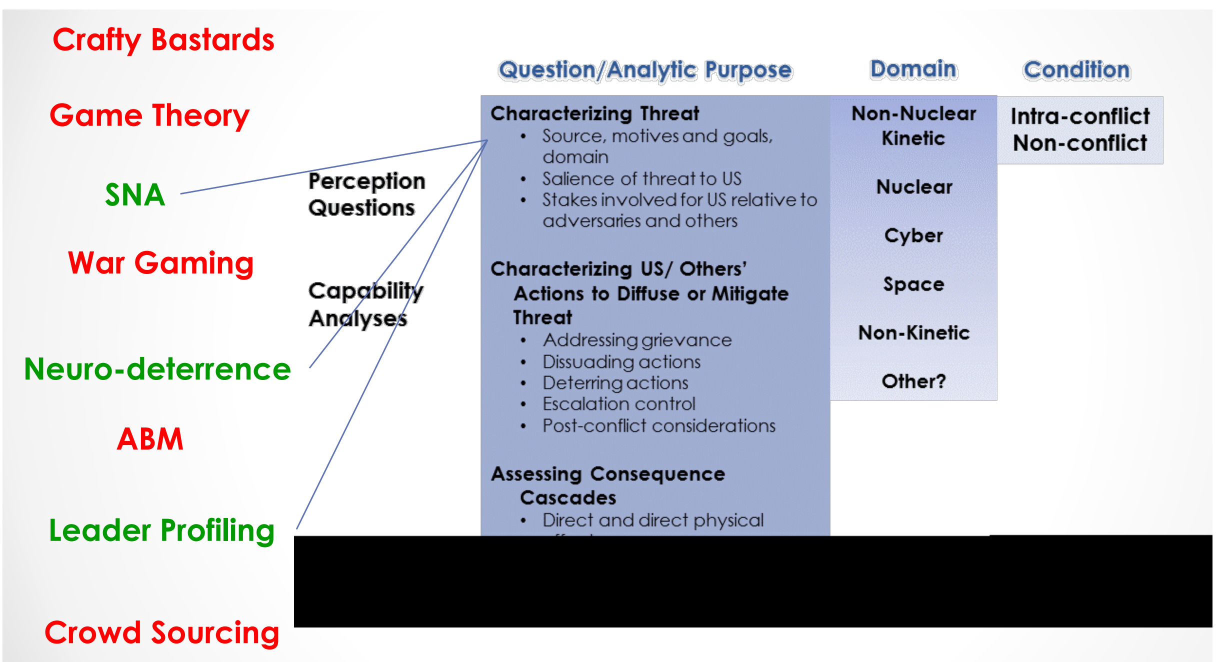

FIGURE 4-1 Characterizing tools, approaches, and methods. SOURCE: Dr. Allison Astorino-Courtois.

[1] "Crafty bastard" war gaming ("blue on red" to test alternative deterrence scenarios) recognizes the challenges of anticipating an intelligent adversary. An example would be a leader of a rogue state employing a "hard to pinpoint" subversive or terrorist organization without national or regional political responsibilities to deploy a "dirty" bomb or small nuclear device to create economic havoc (e.g., take out a major port of entry) or create fear to test national resolve and response.

Dr. Diane DiEuliis, deputy director, Office of Policy and Planning, Office of the Assistant Secretary for Preparedness and Response, U.S. Department of Health and Human Services, provided a presentation titled "Neurobiology and Deterrence: "Neurodeterrence?**"**An abstract of Dr. DiEuliis' presentation is found in Box 4-4.

Dr. John Sawyer, program manager/senior researcher, National Consortium for the Study of Terrorism and Responses to Terrorism, University of Maryland, described the background and current work of this center of excellence for the study of terrorism and responses to terrorism. The center advances knowledge about the causes and consequences of terrorism for homeland security policy-makers. His group within the larger organization is an incubator of innovation that embraces new methodologies and undertakes projects that may have high risk and short deadlines and be very collaborative and operationally focused. He explained one example project—essentially, a case study on ways to influence violent extremists. The methodological approach has three steps: hypothesis identification, micro literature reviews, and generation of a knowledge matrix. The resulting matrix provides access to a wide range of theories and their supporting evidence and offers a tool that could guide concepts and doctrine. Admittedly, this is a very qualitative process.

BOX 4-3

The Crafty Bastard Innovation Cycle and Solution Creation Methodology

CAPT Gail Kulisch (USCG, Ret.), Kiernan Group Holdings

The "crafty bastard" methodology is based on research and case studies which reveal that administrative, bureaucratic structures inhibit design innovation, creating self-induced constraints in a battle against unrestricted adversaries. Disruptive threats, by definition, do not fit an organization's own value chain and innovation cycle. Thinking faster than the speed of threat requires refinement of cognitive agility and the appetite for acceptance of divergent opinions and earned experience. Today's, but more importantly tomorrow's threats, demand an ability to learn more effectively and quickly and out think potential and real adversaries, whether from non-state or state sponsored organizations. Innovative and creative problem-solving design requires new hard skills that are learned through workshop encounters with exceedingly diverse and even rare combinations of talented people who work flexibly and in detail with an array of non-kinetic strategic vectors which offer innovative methods and means for unique problem sets. The crafty bastard process incorporates these critical tenets. It is an 8 week, well-defined development cycle that optimizes these attributes. Unique talent is engaged and includes experienced practitioners from the public and private sector who are practiced in applying learning and experience viewed through unique apertures that imagine new contexts. Initial analysis and assessment is conducted based on focused exploitation of deep open-source materials factoring in culture and context—the new C2 of this environment. Experienced facilitators agitate and guide critical thinking in an open, vendor-agnostic arena guided by carefully crafted questions and content. Actionable recommendations are developed and result in recommendations that disrupt the adversary's adaptation cycle, exploit emerging technologies, and generate operational and tactical level solutions that support Commander's Intent.

BOX 4-4
Neurobiology and Deterrence: "Neurodeterrence?"
Dr. Diane DiEuliis, U.S. Department of Health and Human Services

The past several decades have seen a convergence of neurobiological data with cognitive sciences, psychology and behavioral sciences—largely due to technological advances such as genomics, non-invasive imaging, and the wider availability of expansive data sets. We are thus beginning to bridge neurobiological understanding with the environmental and social backdrop upon which it occurs. An example framework for visualizing this could be the classic "OODA" loop (Observe, Orient, Decide, Act) juxtaposed onto the anatomical backdrop of limbic system function. Further affectors of this framework could be genetic predisposition, genetic heritage, and previous experience. Other fields have adapted this kind of framework for understanding the role of underlying neurobiology in human behavior and decision making, such as the emergent field of neuroeconomics. Some tenants of this field would indicate that human decision making for economics is influenced by relativistic comparisons and perceptions—and is not always rational. Similarly one could apply this framework and understanding to deterrence: understanding the underlying neurobiology that contributes to aggression, and decision making related to "intent to do harm" could provide important inputs to shaping new models and tools for the deterrence community.

Again, many questions and comments arose when the panel presentations were done. One participant asked, "If we know how people behave, does it matter what part of the brain lights up?" Dr. DiEuliis answered that this approach adds another layer of understanding. Another participant noted that, regarding the overall challenge for this workshop, an issue is how we apply neurodeterrence to what is needed for current situations, like headlines about drawing red lines related to Israel and Iran's uranium enrichment. A general issue is how can we use this. Dr. DiEuliis commented that relative to bio-weapons, in nations with lots of deaths due to diseases, bio-weapons are not that worrisome because the population is used to losing lots of people. A participant noted that some leaders are conditioned from childhood to not have empathy for others. Another participant asked whether there is any statistical way to identify some types of behavior. CAPT Kulich answered that red teams have rigor that could be helpful. In a related comment, a participant suggested that an area for research might be to observe behavior during games.

SCENARIO-BASED TOOLS

Dr. Tony Cox, president, Cox Associates, LLC, began the first panel of the second workshop session by noting that scenario-based analytic tools are meant to be used by teams, and those teams must validate both the inputs and the outputs of such tools to be sure they are trusted. A systems engineering approach in terms of an insight-generating model was presented, and analytic approaches in the context of making sense of patterns in big data were discussed. At the end, Dr. Cox explained that these presentations show the types of scenario-based tools available; much infrastructure is in place, and this represents the state of the art.

Lt Gen Robert Elder (USAF, Ret.), research professor, George Mason University, provided a presentation titled "Integrated Influence and Effects Analyses for Use in Deterrence Planning." An abstract of Gen Elder's presentation is found in Box 4-5.

Ms. Anne Russell, director, social systems analysis, SAIC, compared "old-school" analyses of data with newer approaches that augment traditional techniques with new processes, such as social network visualization and analysis techniques as well as chronological or geo-spatial visualizations like Google Earth. Among other benefits, she noted that advanced tools (e.g., a narrative pattern analyzer) can save enormous amounts of time for analysts producing outputs. An illustrative application would be assessing factionalism to help understand the degree of stability or instability of a particular country. Another illustration was use of influence-net modeling for socio-behavioral applications, which can aid reasoning under uncertainty. Ms. Russell added that the effectiveness of any one tool would depend on what the user is trying to do; it is likely that one tool would not be enough for any specific case.

BOX 4-5
Integrated Influence and Effects Analyses for Use in Deterrence Planning
Lt Gen Robert Elder (USAF, Ret.), George Mason University

Timed Influence Nets (TINs), a variant of Bayesian Nets, are used to capture cause/effect relationships that relate timed sequences of actions to the probability of an effect or outcome occurring. TIN models are thus well suited to capture the diverse aspects of nuclear strategy issues. Specifically, TIN models can be used to gain insights into the effects of actions on one or more nuclear strategy objectives and can be adapted to reflect different actors, international environments, phase of military operations, and scenarios. The TIN models can be enhanced through the use of multi-modeling techniques to leverage the ability of multi-agent-based modeling to capture the dynamic interactions among groups. TIN models were used in two service wargames and an Office of the Secretary of Defense-led geopolitical stability study to assess the deterrence and nuclear stability effects of different courses of action across a range of operational phases. The results suggest that such models can be used to inform analyses addressing nuclear policy and strategy questions.

LEADERSHIP PROFILING

Dr. Jerrold Post introduced the panel titled "Leadership Profiling Approaches" for the second workshop session, noting that leadership profiling techniques had already received much attention prior to this session. Also, he noted that trying to understand an opposing side's leadership has deep traditional roots, even though some of the approaches suggested here rightly deserve the "non-traditional" label.[2]

[2]Correctly ascertaining the intentions of an adversary is one of the key reasons why profiling was discussed so thoroughly during the workshop.

Dr. Margaret Hermann, director, Moynihan Institute of Global Affairs, Syracuse University, provided a brief set of remarks titled "Policymakers' Interpretations Matter." An abstract of Dr. Hermann's presentation is found in Box 4-6.

Dr. David Winter, Department of Psychology, University of Michigan, provided a presentation to the workshop titled "Leaders' Drives, Perceptions, and Justifications of Power: Analyzing the Signs in Crisis Situations." An abstract of Dr. Winter's presentation is provided in Box 4-7.

Dr. Stephen Walker, professor emeritus of political science, Arizona State University, provided a presentation to the workshop titled "Tailored Deterrence and Operational Code Analysis." An abstract of Dr. Walker's presentation is found in Box 4-8.

There were many comments, questions, and answers after the three presentations. For example, there was considerable discussion among participants about the pros and cons of hand-coding text versus machine coding; about getting to know the "real" persona versus the "public" persona; and the great amount of material that is available and could be analyzed. As another example, the panel speakers described what they would like to see regarding these techniques, such as (1) an easier coding process (biggest bottleneck); (2) more translations, especially of spontaneous utterances; (3) more tracing of interactions between leaders; and (4) lots of human analysis, which in the end was deemed necessary because one must look at circumstances, public statements, and what the leadership actually does (perhaps the best method). Additionally, the amount of time available to make a decision received attention from the participants—a lot of time means decentralization of power, whereas little time means "act now," which leads to contraction of power.

BOX 4-6

Policymakers' Interpretations Matter

Dr. Margaret Hermann, Syracuse University

The U.S. government employs subject matter experts to assist in the development of models to explore how particular governments are going to respond to deterrent threats and sanctions, which governments are likely to be crisis-prone, and to assess the stability of a government. What if we could, instead or in addition, determine how the leadership itself is likely to interpret a particular situation and to respond? Consider that in the past decade the 29 Asian countries located along the Pacific Rim have had 133 different governments involving changes in the leadership and their orientations to the world. The Profiler Plus software is designed to assess the leadership styles and likely behaviors of such leaders using media interviews with them, their speeches, and their written materials. The techniques have been validated by comparing results with the views of policy makers and diplomats who have interacted with the leaders.

BOX 4-7
Leaders' Drives, Perceptions, and Justifications of Power: Analyzing the Signs in Crisis Situations
Dr. David Winter, University of Michigan

In crisis situations, the intentions of the "other side" are critically important, but they are also difficult to judge. This presentation reviewed research on three concepts and measures relating to power, in order to suggest a way to estimate the aggressive intentions of potential adversaries. (1) High levels of power motive imagery in speeches, diplomatic documents, and broadcast commentaries, for example, are associated with crisis escalation. (2) In escalating crises (as compared with peacefully resolved crises), the implicit perceptions of threat each side exaggerate the threat presented by the other side, as measured by levels power imagery in summaries, précis, or "sound bites" of the other side's statements. (3) Finally, in order to secure acceptance of aggression and war by significant elites, members of the military, legislators, and ordinary citizens, leaders must frame their actions as "just," using the classical criteria suggested by Just War Theory. Taken together, these results suggest that monitoring these three measures—the other side's expression of power in political documents, the exaggerated implicit perception of threat-power in the other side's summaries of own side's statements, and the other side's justification of its power and actions—may help to estimate the intentions of potential adversaries.

BOX 4-8
Tailored Deterrence and Operational Code Analysis
Dr. Stephen Walker, Arizona State University

Tailored deterrence focuses on the problem of tailoring effective deterrence strategies to fit the beliefs, personalities, and cultural norms of diverse target populations regarding the exercise of power. The operational code construct refers to the conceptions of political strategy that inform an agent's decisions, tactics, and strategies in escalating or de-escalating conflict situations. The conceptions are measured as configurations of attributions in the public statements exchanged between agents in a strategic dyad, which index each agent's respective beliefs about the nature of the political universe (friendly or hostile), their degree of control over historical development (low or high), strategic direction (cooperation or conflict), tactical intensity (low or high), and risk-taking orientation (acceptant or averse) regarding the employment of various instruments of power (rewards, promises, threats, and punishments) in strategic interactions. These diagnostic, choice, and shift propensities are modeled formally as subjective games that each agent plays with different allies and adversaries in the political universe. The models indicate when and how members of these strategic dyads will make or respond to deterrent threats and whether such threats are necessary, desirable, or counter-productive.

THREAT ANTICIPATION AND INTELLIGENCE ANALYSIS

Dr. Michael Wheeler's opening remarks for the panel titled “Threat Anticipation and Intelligence Analysis” at the second workshop session gave an overview of the U.S. intelligence community (what it is today and how we got here) and a bit about national intelligence estimates (NIEs, the U.S. “master” estimates). He also framed how Congress got into (and stays in) the intelligence oversight business, not only through the intelligence committees but through studies it mandates, such as the one on China that was in the Fiscal Year 2013 National Defense Authorization Act. Dr. Rich Wagner, emeritus technical staff, Los Alamos National Laboratory, then provided a brief set of remarks, an abstract of which is given in Box 4-9.

BOX 4-9
How Policymakers Utilize Intelligence
Dr. Rich Wagner, Los Alamos National Laboratory

The organizing framework for thinking about U.S. strategic capabilities, including nuclear weapons, is, or should be, warning and response, over timescales ranging from minutes or hours (attack/tactical warning), to many years (strategic or geopolitical warning). The strategy should be to deliberately assess how much warning time we expect to have across this time range, and to have in place the ability to respond adequately within the warning time. This would not be just a reactive strategy; maintaining the capability to respond within warning shapes the current and future security environment. So how should the United States improve intelligence and warning capabilities to support such a strategy? (1) The powerful new capabilities for wide-area, persistent tactical intelligence, surveillance, and reconnaissance developed for Iraq, Afghanistan, and for terror interdiction can and should be adapted for nuclear attack warning and to understand other short-term threat developments short of attack. (2) The intermediate time frame of months to years is especially important for assurance of allies and for regional deterrence. Here, the model should be the NATO ShockWave program of the later phases of the Cold War. In ShockWave, full-scope U.S. and allied national intelligence, coupled with tactical ISR (which was improved expressly for these purposes), was coupled to NATO exercises designed to elicit Warsaw Pact behaviors in their subsequent exercises, in order both to help validate NATO indicator and warning capabilities and to understand changes in Pact operational concepts. (3) Nuclear weapons are mainly relevant for highest-possible-stakes geopolitical challenges of the sort that distinguished the 20th century. Since the end of the Cold War, we have been in a "strategic pause," and the question is when (if ever) and how (if at all) some highest-stakes geopolitical challenge might emerge in the future. Over the past several decades (and perhaps always), major geopolitical shifts have almost never been anticipated. "Path-gaming"—geopolitical games with notional time-scales of years or decades—have had some utility, and should be rejuvenated.

The current U.S. nuclear weapon posture is poorly suited to both near-term extended deterrence/assurance and some future major geopolitical challenge. Its main value is as a basis and starting point for its own future reconfiguration, if and when that is needed, and it should be managed expressly with that in mind.

Mr. David Hamon, principal, National and International Security Strategies, Analytic Services, Inc., provided a brief set of remarks titled "Threat Anticipation." An abstract of Mr. Hamon's remarks is found in Box 4-10.

Additional dialog among the participants surfaced other key issues, such as a need to focus on non-negotiated monitoring; a need for more effort in pulling signals out of clutter; the fact that nuclear applications need some sort of monitoring test bed; despite all the work on threat anticipation there was surprise by the "sprint-to-zero" emphasis; and—at the end of the day—humans make decisions, so there is a need to look at and understand human behavior.

BOX 4-10
Threat Anticipation
Mr. David Hamon, Analytic Services, Inc.

To Identify and develop social sciences-based research and analyses to support the anticipation and reduction of weapons of mass destruction (WMD) and related threats along a rolling long-term horizon, the Advanced Systems and Concepts Office (ASCO) of the Defense Threat Reduction Agency (DTRA), undertook a Threat Anticipation Project (TAP). Since its inception in 2002, ASCO has initiated TAP projects to explore productive areas of threat anticipation, including workshops to identify and acquire relevant expertise from the social science, computational science, and other communities; development of conceptual computer models to better understand and anticipate asymmetric threats; and staff activities involving networking with universities and other federal and private sector organizations to survey the current thinking on these issues and leverage outside expertise. TAP has produced a variety of concepts, computer and theoretical models, workshop proceedings, and reports of value to the future mission needs of DTRA. It is extremely important to have these products preserved, validated in some practical sense, and more widely used within the larger national security community. Threat anticipation by computational and social sciences is rapidly gaining recognition for potential utility; hence, TAP can become a major contributor to the Department of Defense, other federal agencies, universities, and other organizations in this area.

5

Insights for the Future

At various times during the workshop, especially at the end of the day and at the end of a session, many issues relating to strategic nuclear deterrence, the usefulness of various analytical tools, and the content of a possible follow-on consensus study were discussed by workshop participants. The sections below summarize collections of such comments by individual workshop participants, particularly those who attended the entire workshop and contributed significantly to the summary sessions. These comments reflect the considerable diversity of opinions expressed during the workshop on a range of issues. The last section contains illustrative terms of reference for a possible follow-on study.

INSIGHTS OF VARIOUS INDIVIDUAL WORKSHOP PARTICIPANTS

On Deterrence

Many participants noted that strategic deterrence, as with strategic stability, means different things to different people and that strategic deterrence is not simply the nuclear deterrence of the Cold War. The nuclear dimension, however, was the key focus of this workshop. While strategic use of conventional weapons is clearly an alternative to nuclear use, the participants did not focus on other things that could be used in a campaign. To illustrate the range of views expressed by the participants, one view was that the record shows the Russians always overestimated the United States, not so much in capability but more likely in resolve. Another view was that a rich set of challenges currently exist, such as how can the United States verify what weapons China possesses, given its extensive underground tunnels.

On General Chambers' Presentation

Gen Chambers asked, "What is it we give to the President to deter and assure? We need to develop and foster critical thinking on deterrence and assurance." These notions align with one of the Air Force's important vectors. He also reminded the participants that an examination and critical evaluation of appropriate analytic tools would be of great value to the Air Force in understanding its mission of organizing, training, and equipping two legs of the strategic triad.

On General Klotz's Presentation (Nuclear Posture)

Gen Klotz believes the administration's orientation has been clear, and there has been some consensus in Congress, but it is fragile. A participant indicated that, although the orientation is "toward" global zero, there are lots of cautions about maintaining a reliable and secure force in the meantime. A major concern also raised by this participant was that the budget tightening will lead to increased disagreements. That participant also noted that Gen Klotz partially bought into the argument that the India-Pakistan proliferation might conceivably have been avoided had the world had its act together on the Treaty on the Non-Proliferation of Nuclear Weapons and the Comprehensive Nuclear-Test-Ban Treaty, for example. On that point the participant was extremely skeptical.

A participant believed this was a very interesting presentation on the relevant issues to deterrence but noted that Gen Klotz seemed to argue for status quo with no reduction in resources, which did not seem realistic. Also, he noted that Gen Klotz did not address how to do more with less. Another participant noted that Gen Klotz's message was to not get hung up on Global Zero rhetoric; U.S. policy is not to go there unilaterally and to keep nuclear weapons safe, secure, and effective so long as others have nuclear weapons. But, that participant argued that strategy will not drive decisions made in an austere budget climate by politicians with higher priorities than nuclear deterrence. Noting that Gen Klotz believes the time is right for establishment of a new national consensus on the support and sustainment of nuclear deterrence, a participant observed that this will require two schools of thought to agree (those who say nuclear weapons are needed and those who advocate the elimination of all U.S. nuclear weapons); can both be satisfied? He concluded that this will require fact-based analysis plus the tools of such analysis.

On Congressional Perspectives

Ms. Woolf's candid presentation during the second session elicited many favorable comments, as summarized below. She indicated there tends not to be a congressional perspective, per se. Ms. Woolf noted that nuclear weapons do not have a high profile among members and that institutional knowledge has decreased over time as important members and staff members that were present during the Cold War era have retired. As a result, she stated members tend to vote along the same lines as the more knowledgeable members, which has the advantage of meaning fewer people need to be convinced. Ms. Woolf also stated that the reasoning used by staffs, often driven by advocacy groups, reflects first-order arithmetic only, which can be misleading because these calculations do not take into account underlying strategic, conceptual, or operational issues. It is possible, she argued, to change their focus, sometimes, but analysis has to be convincing and relevant to home districts or budgets.

The participants agreed that Ms. Woolf gave a fascinating description of the congressional process and explained the difficulty involved in getting traction for deterrence issues. One participant summed it up as follows: "Congress 101" means this: youth, other priorities, the Cold War took place in "ancient" times, nuclear non-proliferation and security are today's problems; what's in it for my district? cut the deficit; follow the leader, but who will lead as the experienced ones leave Congress? The participant added that the information age empowers non-governmental organizations and bloggers—a challenge for getting sound analysis into the decision process.

A participant voiced the need for showing how the maintenance of deterrence force structure at appropriate numbers can in fact be useful to a particular interest of someone who would otherwise advocate the sharp reduction or elimination of such weapons. Ms. Woolf's response was to postulate outcomes of deterrence that help satisfy something else of interest to a would-be detractor.

On Tools In General

Several participants identified many tools that may be of value to the Air Force (see Box 5-1), and many comments during the sessions related to them. A synopsis of those comments follows.

A general view by several participants was that it would be of interest to look for a suite of complementary tools and then close the aperture on bounds for possible decision making. It could be useful to do many of these, but some participants stated that they did not know how to work in some of the military environments or how it might work in a classified setting. Many participants believed they must know what information is needed and what tools could be used to get it.

Other views were as follows. One participant noted that a lot of the problem is that theory and data to support such tools is not there. Validation of such tools is most important; one would like empirical validation to be 90 percent, but there will never be an empirical way to prove some of this. Users will have to be exposed to different elements as bounding mechanisms. Another participant pointed out that there has to be some assessment of these things; how much can they be trusted? For many methods, one needs to see what works with real people.

A pessimistic view from one participant was that most of this is not ready for use now. Numbers from some of the decision tools may be worse than random. On the other hand, a more positive view came from another participant who noted that there is a huge amount of information available on new analytic techniques that is just beginning to be tapped. New concepts and methods should continue to be searched for and examined, even if some might at first be considered wild and crazy. Other participants affirmed that the real value is considering types of data that can be generated to attribute motives and perspectives to various entities (e.g., adversarial nations, terrorists). Social neuroscience research is showing "us-them" reactions and is very interesting relative to combat and ethical or moral dilemmas.

Regarding the notion of using neuroscience, a concern expressed was that one must worry about biases. A person steeped in deterrence thinking may not behave the same as a college student getting paid by the hour. Also, a lot of these studies are based on trivial tasks, which are unlikely the same as complex international tasks. One participant stated that psychological studies largely represent averages over many people, but some risk seekers and

BOX 5-1
List of Analytical Tools Considered During the Workshop

A key focus of the workshop was to identify different techniques or methods the Air Force might use in addressing strategic deterrence capabilities. At least 16 approaches were discussed:

- Qualitative analysis (international relations/strategic studies/estimative intelligence);
- Historical case studies;
- Historical statistical-empirical analysis;
- Operations research;
- Simulations and war games;
- Game theory;
- Simple deterrence analysis using synthetic cognitive models;
- Actor-specific behavioral modeling and leadership profiling;
- Agent-based computational modeling (both simple and complex cognitive decision models);
- Social network analysis/influence diagrams/data mining;
- Subject-matter-expert elicitation;
- Crowd sourcing;
- “Evil genius” and “crafty bastard” efforts;
- Insights provided by neurobiology as related to behavior;
- Heuristics; and
- Systems engineering models.

NOTE: In light of Dr. Todd's beliefs regarding the value of "simple heuristics," at least one expert cautions that with projected advances in computational capabilities, such as exaflop computing by 2020 or sooner, there will be a temptation to take a systematic modeling approach to address the higher-order complexities of deterrence techniques and capabilities.

others have different characteristics, which are not suitable for specific situations. A counter view was offered that, nevertheless, some data may be able to narrow the possibilities. Some blending of historical record and profiles with some of these techniques could have value, but one must be sure not to set decision makers up with biases.

On Profiling (Including the Panel Presentation)

Some believed strongly that there should be no shortfall on resources devoted to developing leadership profiles, which are crucial. They noted that profiling can identify tendencies, trends, and patterns, but it is not for predicting. Psychological operations are very important (for example, telling a population about luxurious life-styles of its leaders), and it is unimaginable to not know about a leader. They concluded that to augment Department of Defense decision making, more must be known about leaders. More intense intelligence effort is needed to get at closed societies.

Other participants were not convinced that profiling had significant value in all deterrence contexts, believing instead that more information is not necessarily better. Not all insights are useful; they must be tested along the way. Nevertheless, others thought profiles by different teams might help. There is merit to seeing how the other analytical tools discussed might help with profiling; social networking tools, such as sentiment mining, could play a big role in understanding adversaries and their populations. According to several participants, how to make these tools more robust is a big issue. Profiles appear to fit well with social networking tools.

The panel on leadership profiling approaches was held during the second workshop session. Drs. Winter, Walker, and Hermann mentioned being frustrated in their work by the insufficiency and immaturity of computer-based coding software plus the difficulty and time-sink of translating documents to be coded into English. A participant thought it would be better to have coding schema and tools that could handle documents in native language, but natural language coding is not there yet. Several participants believed these speakers did good work and that this is worth looking at further. They argued that the various leadership profiling approaches used in concert can yield an outcome greater than the sum of its parts.

Additional points of view were as follows. One participant stated that textual analysis—for example, use of verbs, power language, and other linguistic clues—has already been developed in some detail. These methods appear to be potentially useful for recognizing changes in leader (and influencer) attitudes and intentions based on their published speeches and remarks. A related point was made that inter-judge concordance is already high enough to suggest that these methods have some reliability. That participant also claimed that interpretation of historical experience suggests that leader language may help to predict aggressive versus less aggressive actions in escalating or resolving conflicts. Careful independent validation of these methods may be useful in determining whether they are ready for use in the context of deterrence. Extensions to detect shifts in the thinking of key influencers and shifts in power among factions, as well as hardening, softening, or changing positions or intents of factions, might be especially valuable.

Dr. Hermann and the other two panel members described approaches to leadership profiling. Although she gave fewer details than the other two, a participant thought Dr. Hermann’s approach could be more amenable to computer tagging. Most thought all three panelists' work could be very useful in improving deterrence. It was noted that Dr. Winter's approach requires manual labeling of concepts from a taxonomy that includes concepts such as power imagery. He provided quantitative support for his work and noted that since it requires manual labeling it is difficult to use it with social media sources, but it could be very useful with selected document sources. A participant noted that Dr. Walker presented a very similar approach to Dr. Winter's and suggested that both approaches can be automated, but there was not a chance to discuss it further.

On Heuristics

Dr. Todd gave a presentation on an important topic. In addition to a learning tool for analysts, a participant wondered if there could be a way to help planners learn about decision biases? Another participant noted that heuristics have been shown to provide value as an aid in decision making in a variety of enterprises—but not yet in strategic deterrence. His additional views were that the key would be to pick the right heuristics and to know when and when not to rely on them; use of the wrong heuristics could be disastrous if the wrong one is picked; and application of subject-matter expertise is essential.

Participants also noted that Dr. Todd showed how, in some instances, less information is better than more. He pointed out that simpler algorithms can outperform more complex ones and provide answers in a shorter time.[1] He also described his ongoing work in cognitive bias amelioration as part of the Intelligence Advanced Research Projects Agency's *Sirius* program. Another participant observed that fast, frugal heuristics have proven useful for some problems—for example, guessing which cities are biggest based on recognition. However, they have not been studied yet in the context of deterrence (or other game theory settings, such as multi-way negotiations, or formation of a consensus decision starting from factions with different preferences). The participant added that understanding fast, frugal heuristics for conflict escalation and resolution (if they are used by people in reality) could be useful.

On Force Structure Analyses

Mr. McKenna described U.S. Strategic Command's (STRATCOM's) generic approach to analysis of force structure issues. Strategy should come first because it drives results. A participant noted that the reason for this is that they do "requirements analysis," which assesses ability to do a well-specified job, rather than characterizing capability. The participants understood that the USSTRATCOM approach handles the kinetics pretty well, but it has not done very well on issues relating to individual decision makers, political context, and world environment. USSTRATCOM does, however, consider different futures and conduct an "attribute" based parametric analysis. Regarding Mr. McKenna's framework for thinking about deterrence, the most interesting component according to some participants was his explicit separation of the overall deterrence process into ends/ways/means. He showed how to link policy/strategy to outcomes; sound analysis from two different staffs (USSTRATCOM and A9). It was also understood by the participants that sorely lacking with this type of analytical approach is an ability to understand adversary perceptions and intentions. This lack is in great contrast to the well developed ability to understand an adversary's capabilities.

On the Approach of the Air Force Office of Studies and Analyses, Assessments, and Lessons Learned

Maj Sorice described his organization's systematic efforts to analyze the implications of lower force levels across many possible conflicts with different strategies. The primary

[1]While not stated explicitly during the workshop, some experts caution that the power of computation should not extend beyond the power of comprehension. However, one should not discount the understanding that may come from modeling and simulating highly complex problems. With the expected progress over the next decade in "reverse engineering" the human brain, one can expect rapid progress in expanding "natural bridges" between what the human brain can do best with what the computer can do best.

takeaway according to many participants was a table showing that the ability to support various classic targeting options changes (or disappears) at lower force levels. The analyses were not discussed in detail; instead, Maj Sorice presented a rather detailed assessment of force postures by numerous metrics across the uncertainty space (because of concerns about classification, there were no numbers given). Participants believed his presentation offered a framework for thinking about deterrence. They noted that there were no analytic inputs (i.e., no weights associated with items), but it appeared to be a pretty complete framework for analyzing deterrence approaches. A participant observed that Maj Sorice showed how to link policy/strategy to outcomes; again, sound analysis was provided by two different staffs (USSTRATCOM and A9). The A9 organization is expecting to drive forward in fleshing out and applying the analytic framework it presented.

On Scenario-Based Analytic Tools

Gen Elder described complex modeling that is state of the art, but at least one participant questioned how it can be validated, asking, “What are the criteria for selecting subject-matter experts?” Gen Elder described an analytic framework that he developed, but at least one participant had difficulty understanding the details of its use and could not assess the value of the approach. He noted that models and integrated ensembles of models for generating insights are already available, such as Pythia, Construct, and the framework developed by the *Concepts and Analysis of Nuclear Strategy* study. A participant's view was that these models generally have uncertain validity and stop short of supporting decisions, except by providing possibly useful (but possibly misleading) insights into connections among variables. More expressive models and better validation are probably essential for closing the gap between insight and well-supported decisions.

Ms. Russell described interesting analytic tools, including Narrative Pattern Analyzer (NPA) and Influence Net Modeling (iNET/SIAM™), which show the power of new methods. A workshop participant believed, however, that it was unclear how they would be readily adapted to nuclear deterrence. Another workshop participant believed that the more useful one of the two for the purposes of this workshop appeared to be SIAM™. It provides a Bayesian framework for improving estimates with incoming information and appears capable of being employed for deterrence work with modest effort. Another participant suggested that software such as iNET and Palantir make it practical to track patterns in space and time. NPA and similar software may provide valuable clues about emerging patterns and potential threats, including shifting attitudes toward use of nuclear weapons.

On Threat Anticipation and Intelligence Analysis

Although one participant did not see any takeaways from the panel on threat anticipation and intelligence analysis, a few observations were offered. Dr. Wagner sees strategic forces as a training base for the United States to maintain knowledge and skills until—perhaps decades from now—there is again a need for "real" nuclear forces. Dr. Wagner believes we are in a strategic pause and need to be ready with appropriate analysis and analytic tools when we come out of this period. Another participant noted that Dr. Wagner did present an additional framework, the most interesting part of which was identification of a matrix that breaks up deterrence situations into four elements—negotiated monitoring/not versus treaty verification/threat.

Mr. Hamon's experience could be very valuable in developing a tool taxonomy in the future. Another participant believed there are limitations of the estimative process (manage expectations—it gets back to understanding intentions). That participant also noted that a Defense Science Board study of nuclear monitoring is expected to be available soon, and many nuclear-related studies sponsored by the DTRA's Advanced Systems and Concepts Office were done over a decade or so.

INSIGHTS FOR A FOLLOW-ON STUDY

During both workshop sessions, but especially the second, workshop participants offered many insights regarding the content of a possible follow-on study. The dialog focused on an illustrative TOR that could form a framework for such a study. Several versions of this TOR were discussed and modified during the workshop, taking into account a wide range of individual views of the participants. The notional TOR in Box 5-2 reflects comments from various participants and could serve as a starting point for decisions by the Air Force and National Academies regarding a follow-on study. During discussion of the TOR, two other suggestions offered by workshop participants were (1) for the longer-term study, why could it not look at simulation scenarios and games to see what tools might work, and (2) the study could begin with a presentation of the security environment by using a geographical schema to present conditions in applicable areas of interest; deterrence matters should be considered region by region as well as in a strategic sense.

BOX 5-2
Notional Terms of Reference for a Follow-on Study

As identified during the workshop, possible items in the terms of reference for a follow-on study by an ad hoc committee were as follows:

1. Identify the broad issues and factors that must be considered in seeking nuclear deterrence in the 21st century. Describe a program of analysis to address those issues and support planning, resourcing and managing U.S. nuclear deterrence in the 21st century.
2. Identify the major components of the analysis and the relationships among them to serve as a basis for the identification, development and use of necessary tools and methods.
3. Evaluate and recommend tools, methods, including behavioral science-based methods, and approaches for improving the understanding of how nuclear deterrence works in the 21st century, how it might fail, and how failure might be averted by the proper choice of capabilities, postures, and concepts of operation of American nuclear forces.
4. Recommend a way ahead for evolving and adapting methods and approaches in a coherent, systematic approach. This will include identifying what questions need to be addressed, and assessing what questions each tool, method, or approach is most and least valuable for this purpose.
5. Recommend how these methods and approaches can be drawn upon as a package, or used to inform each other. It is likely that any tool, method, or approach will have strengths and weaknesses.
6. Recommend criteria and a framework for validating the tools, methods, and approaches and for identifying which classes of tools, methods, and approaches are the most promising.
7. Recommend a balance of resourcing across the classes in today's austere financial climate and that can be reserved for future resourcing when and if it becomes available.

NOTE: While the workshop committee did engage in much discussion between the two workshop sessions on what could constitute the basis for the TOR of a follow-on study, the TOR reflects a much broader discussion that occurred at both workshop sessions among the many participants.

Appendix A

Biographical Sketches of Committee Members

Gerald F. Perryman, Jr. (Maj Gen, USAF, Ret.), *Chair,* is currently an independent consultant. Upon concluding military service in 2002, Gen Perryman joined Raytheon Company as vice president and lead executive for the company's Intelligence Surveillance and Reconnaissance (ISR) Strategic Business Area, McKinney, Texas. There he developed strategies for ISR growth using capabilities from across that diverse, global company, helping Raytheon to provide integrated mission systems for its many customers. From 2006 to 2011 he was director of strategic pursuits for Raytheon Intelligence and Information Systems in Garland, Texas, forming and leading teams for competitive capture of key command and control, space operations, and ISR opportunities. Prior to his Raytheon work, Gen Perryman was assistant deputy chief of staff, warfighting integration, Headquarters Air Force, providing guidance and direction for transforming Air Force warfighting capability by integrating command and control, communications and computer networks, and intelligence, surveillance, and reconnaissance systems. Earlier Gen Perryman led the Air Force's Aerospace Command and Control and ISR Center at Langley Air Force Base, Virginia. He served as commander of the 14th Air Force, which encompasses all Air Force space operations forces worldwide. Gen Perryman received his MBA from the University of North Dakota. He currently serves on the National Research Council's (NRC's) Air Force Studies Board and is a past member of the Committee on Examination of the Air Force Intelligence, Surveillance, and Reconnaissance (ISR) Capability Planning and Analysis (CP&A) Process.

Rafael Alonso is a vice president and division manager for the Autonomy and Analytics Division of Science Applications International Corporation (SAIC), where he manages a staff of more than 140 researchers and engineers in the areas of analysis, computer vision, neuroscience, robotics, remote sensing, biometrics, social media, visualization, and information systems. Dr. Alonso is also an SAIC technical fellow. Dr. Alonso joined SAIC in 2010, when SAIC acquired his previous company, SET Corporation. At SET, Dr. Alonso served as senior vice president and director of SET's Information Systems and Security Division. Prior to joining SET, Dr. Alonso was part of the management staff at Sarnoff Corporation. As technical director of Sarnoff' Convergence Laboratory, he was responsible for overseeing a staff of 40 employees with externally funded research projects in a number of areas, including multimedia storage and databases systems, web information systems, machine learning and user modeling, video quality, video compression, digital cinema, and targeted advertising. Prior to joining Sarnoff, Dr.

Alonso co-founded the Matsushita Information Technology Laboratory (MITL) in Princeton, N.J., where he served in various roles including Associate Director and Senior Scientist. At MITL, he developed leading edge information and video systems for Panasonic. Dr. Alonso started his career as an Assistant Professor in the Computer Science Department of Princeton University, where he graduated several doctoral students, and co-developed new courses in database technology and distributed systems. He has published over 50 scientific papers in information and knowledge management topics, and is currently an SAIC Fellow. Dr. Alonso obtained his B.A. in mathematics and computer science from New York University, an M.S. in electrical engineering from Columbia University, and a Ph.D. in computer science from University of California, Berkeley.

Allison Astorino-Courtois is executive vice president of National Security Innovations, Inc. (NSI), and has more than 16 years of experience in quantitative political science and decision theoretic research. Dr. Astorino-Courtois has provided lead technical management and core support for a five Department of Defense (DoD) Joint Staff and U.S. Strategic Command (USSTRATCOM) Strategic Multi-layer Analysis (SMA) projects including recently completed Competing Analysis of Nuclear Strategy for USSTRATCOM and Influencing Violent Extremist Organizations for U.S. Central Command. She has also worked a refocusing of DoD deterrence planning to the decision calculus of the actor(s) to be deterred and has designed and produced of a second- and third-order effects analysis methodology tool for military analysts and planners. Prior to joining NSI, Dr. Astorino-Courtois worked for SAIC, where among other tasks she served as a USSTRATCOM liaison to U.S. and international communities. Prior to SAIC, Dr. Astorino-Courtois was a tenured associate professor of international relations at Texas A&M University, where her research focused on the cognitive aspects of foreign policy decision making. She has received a number of academic grants and awards and has published articles in multiple peer-reviewed journals, including *International Studies Quarterly, Journal of Conflict Resolution, Political Psychology, Journal of Politics and Conflict Management*, and *Peace Science*. She has also taught at Creighton University and as a visiting instructor at the U.S. Military Academy at West Point. Dr. Astorino-Courtois earned her Ph.D. in international relations/research methodologies from New York University.

W. Peter Cherry is an independent consultant who retired in 2010 as the chief analyst on the U.S. Army's Future Combat Systems Program at SAIC. He was responsible for analytic support to requirements analysis, performance assessment, and design trades. Previously, Dr. Cherry was leader of the Integrated Simulation and Test Integrated Program Team, focusing on test and evaluation planning, the development of associated models and simulations, and the development of the Future Combat System of Systems Integration Laboratory. He was a participant in the Future Combat Systems Program from its inception, leading analysis and evaluation of concepts as a member of the Full Spectrum Team during the contract activities that preceded concept and technology development. Since the completion of his studies at the University of Michigan, Dr. Cherry has focused on the development and application of operations research in the national security domain, primarily in the field of land combat. He contributed to the development and fielding of many of the major systems employed by the Army, ranging from the Patriot Missile System to the Apache helicopter, as well as command control and intelligence systems such as ASAS and AFATDS. In addition, he contributed to the creation of the Army's Manpower Personnel and Training Program (MANPRINT) and to the Army's Embedded Training Initiative. His recent research interests include Peacekeeping Operations and the development of transformational organizations and materiel. Dr. Cherry was a member of the Army Science Board and served as chair of the Board's Logistics Subpanel. In addition he has participated over the past 10 years in independent reviews of the Army's Science and Technology programs and on NRC studies addressing a variety of defense issues. Dr. Cherry received a Ph.D. in industrial engineering from the University of Michigan. He is currently a member of the Board on Army Science and Technology, a fellow of INFORMS, and a member of the National Academy of Engineering (NAE).

Louis Anthony Cox, Jr., is president of Cox Associates, a Denver-based applied research company specializing in quantitative risk analysis, causal modeling, advanced analytics, and operations research. Since 1986, Cox Associates' mathematicians and scientists have applied computer simulation and biomathematical models, statistical and epidemiological risk analyses, causal data mining techniques, and operations research and artificial intelligence models to measurably improve health, business, and engineering risk analysis and decision making for public and private sector clients. Since 1996, its sister company, NetAdvantage, has provided operations research services and software for telecommunications companies. In 2006, Cox Associates was inducted into the Edelman Academy of the Institute for Operations Research and Management Science, recognizing outstanding real-world achievements in the practice of operations research and the management sciences. In 2012, Dr. Cox was inducted into the NAE "for applications of operations research and risk analysis to significant national problems." He has been honorary full professor of mathematics at the University of Colorado, lecturing on biomathematics, health risk modeling, computational statistics, and causality. He is on the faculties of the Center for Computational Mathematics and the Center for Computational Biology at the University of Colorado, Denver and is now a clinical professor of biostatistics and informatics at the University of Colorado Health Sciences Center. Dr. Cox holds a Ph.D. in risk analysis (1986) and an S.M. in operations research (1985), both from the Massachusetts Institute of Technology (MIT); an A.B. from Harvard University (1978); and is a graduate of the Stanford Executive Program (1993). He is a member of the NRC Board on Mathematical Sciences and Their Applications and a member of the Standing Committee on the Use of Public Health Data in FSIS Food Safety Programs.

Paul K. Davis is a senior principal researcher at the RAND Corporation and a professor of policy analysis in the Pardee RAND Graduate School. His research interests include strategic planning and methods for improving it, decision-making theory, counterterrorism, and advanced methods of analysis and modeling (notably exploratory analysis and multi-resolution modeling). He has authored or coauthored widely read books on defense planning, capabilities-based planning, portfolio analysis, and deterrence and influence theory, as well as an integrative review on social science for counterterrorism. Before joining RAND, Dr. Davis was a senior executive in DoD. He has served on numerous national panels for DoD, the National Academies, and the intelligence community. He also is a regular reviewer on several professional journals. He received his Ph.D. in chemical physics from the MIT. Dr. Davis served as a member of the

NRC Committee on Conventional Prompt Global Strike Capability and as a member of the Committee on Modeling and Simulation for Defense Transformation.

Jerrold M. Post is professor of psychiatry, political psychology, and international affairs and director of the Political Psychology Program at George Washington University. Dr. Post has devoted his entire career to the field of political psychology. Dr. Post came to George Washington after a 21-year career with the Central Intelligence Agency where he was the founding director of the Center for the Analysis of Personality and Political Behavior. He played the lead role in developing the "Camp David profiles" of Menachem Begin and Anwar Sadat for President Jimmy Carter and initiated the U.S. government program in understanding the psychology of terrorism. In recognition of his leadership at the center, Dr. Post was awarded the Intelligence Medal of Merit in 1979. He received the Nevitt Sanford Award of the International Society of Political Psychology in 2002 for Distinguished Professional Contributions to Political Psychology. In December 1990, he testified before the House Armed Services Committee and the House Foreign Affairs Committee on the political personality profile of Saddam Hussein he had developed. Since 9/11, he has testified on the psychology of terrorism before the Senate, House, and the United Nations. Dr. Post has written or edited 10 books, including *The Psychological Assessment of Political Leaders, Leaders and their Followers in a Dangerous World,* and *The Mind of the Terrorist,* and he contributed the lead chapter on “Actor-Specific Behavioral Models of Adversaries: A Key Requirement for Tailored Deterrence” in *Tailored Deterrence: Influencing States and Groups of Concern.* He is a frequent commentator in national and international media on such topics as the psychology of leadership, the psychology of terrorism, weapons of mass destruction, Osama bin Laden, Hugo Chavez, Mahmoud Ahmadinejad, Kim Jong Il, Muammar Qaddafi, and, most recently, Bashar al-Assad. Dr. Post received his baccalaureate degree magna cum laude from Yale College. After receiving his medical degree from Yale, where he was elected to Alpha Omega Alpha, honor medical society, he received post-graduate training in psychiatry at Harvard Medical School and the National Institute of Mental Health.

Brian Skyrms is a distinguished professor of logic and philosophy of science and economics at the University of California, Irvine, and a professor of philosophy at Stanford University. He has worked on problems in the philosophy of science, causation, decision theory, game theory, and the foundations of probability. Most recently, his work has focused on the evolution of social norms using evolutionary game theory. His two recent books, *Evolution of the Social Contract* and *The Stag Hunt,* are both on the topic of the workshop. These books use arguments and examples from evolutionary game theory to cover topics of interest to political philosophy, philosophy of social science, philosophy of language, and the philosophy of biology. Dr. Skyrms is a fellow of the American Academy of Arts and Sciences and one of just three living philosophers (along with Allan Gibbard and Patrick Suppes) to be elected a fellow of the National Academy of Sciences.

Michael O. Wheeler is a member of the senior research staff at the Institute for Defense Analyses (IDA), and since 1991, a member of the Strategic Advisory Group at USSTRATCOM. A 1966 graduate of the U.S. Air Force Academy, Dr. Wheeler retired in 1991 at the rank of Colonel. While in the Air Force, he served in Tactical and Strategic Air Commands, in Thailand during the Vietnam War, on the Air Staff, at the National Security Council and State Department, on the faculty of the U.S. Air Force Academy, and on the Joint Staff. At time of retirement, he was the arms control advisor to the chairman of the Joint Chiefs of Staff. In 1978-1979, Dr. Wheeler was a White House fellow. Following retirement from the Air Force, Dr. Wheeler joined strategic studies centers, first at System Planning Corporation, then at SAIC, and then at IDA. Dr. Wheeler also has served on Defense Science Board task forces and on the advisory committees for Lawrence Livermore National Laboratory and the National Nuclear Security Administration. He was the executive secretary of the congressionally chartered Commission on Nuclear Expertise (aka the Chiles Commission), and from 2006 to 2008, he was director of the Advanced Systems and Concepts Office at the Defense Threat Reduction Agency. He has published broadly in national security affairs. Dr. Wheeler holds a Ph.D. in philosophy from the University of Arizona.

Appendix B

Workshop Session Agendas

SESSION 1
SEPTEMBER 26-28, 2012
WASHINGTON, D.C.

September 26, 2012

0900 Vision for the Workshop
- Maj Gen William Chambers, Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration, Headquarters U. S. Air Force, *Workshop Co-Champion*

0930 Welcome and Introductions
- Maj Gen (Ret.) Gerald Perryman, Jr., Independent Consultant

1015 Incentives for Nuclear Non-peer to Consider “First Use” of Nuclear Weapons During a Conventional Conflict with the United States or its Allies
- Dr. Daryl Press, Associate Professor, Department of Government, Dartmouth College

1115 Tailored Deterrence
- Dr. Barry Schneider, Retired Director, U.S. Air Force Counterproliferation Center

1215 Continue Discussions *with lunch available*

1300 AFGSC/CC Vision of 21st Century Deterrence
- Lt Gen James Kowalski, Commander, Air Force Global Strike Command, *Workshop Co-Champion*

1400 Saddam Hussein’s Views on the Role/Utility of Nuclear Weapons and Perceptions Influencing His Decision Making
- Mr. David Palkki, Deputy Director, Conflict Records Research Center, National Defense University

1515 Where Are We Now? What Is Useful?
- Mr. Hunter Hustus, Technical Advisor, HQ USAF/A10—Strategic Deterrence and Nuclear Integration

1615 Workshop Committee Feedback to Day 1 Presentations
- All

1700 Adjourn

September 27, 2012

0900 Actor-Specific Behavioral Models of Adversaries: A Key Requirement for Tailored Deterrence
- Dr. Jerrold Post, Professor of Psychiatry, Political Psychology, and International Affairs and Director of Political Psychology Program, George Washington University

1015 Panel 1—Analytic-based Approaches for Deterrence Analysis
- Dr. Rob Axtell, Chair, Computational Social Science Department, George Mason University
- Dr. Rita Parhad, Associate Partner, Monitor360
- Dr. Rafael Alonso, Vice President and Division Manager, Autonomy and Analytics Division, Science Applications International Corporation (SAIC)

Moderator: Dr. Paul Davis, The RAND Corporation

1215 Continue Discussions *with lunch available*

1315 Panel 2—Deterrence Concept Updates and Approaches
- Dr. Elbridge Colby, Research Analyst
- Mr. Patrick McKenna, Chief, Plans Evaluation and Research Division, U.S. Strategic Command (USSTRATCOM)
- Mr. Orde Kittrie, Senior Fellow, Foundation for Defense of Democracies and Professor of Law, Sandra Day O'Connor College of Law, Arizona State University

Moderator: Dr. Michael Wheeler, Institute for Defense Analyses

1530 Workshop Committee Feedback to Day 2 Presentations
- All

1700 Adjourn

September 28, 2012

0900 Panel 3—Non-Traditional Approaches to Deterrence
- Dr. Diane DiEuliis, Deputy Director, Office of Policy and Planning, Office of the Assistant Secretary for Preparedness and Response, U.S. Department of Health and Human Services
- CAPT (Ret.) Gail Kulisch, Owner and Managing Principal of BTG Ventures, LLC
- Dr. John Sawyer, Program Manager/Senior Researcher, National Consortium for the Study of Terrorism and Responses to Terrorism, University of Maryland

Moderator: Dr. Allison Astorino-Courtois, National Security Innovations, Inc.

1100 Workshop Committee Feedback to Day 3 Presentations
- All

1200 Continue Discussions *with lunch available*

1230 Capstone: Future Strategic Nuclear Deterrence and National Security Challenges for the United States
- Dr. C. Paul Robinson, President Emeritus, Sandia National Laboratories

1300 Planning for Session 2

1400 Adjourn

SESSION 2
JANUARY 29-31, 2013
WASHINGTON, D.C.

Objectives

1. Receive briefings on topics related to the workshop terms of reference (TOR)
2. Participate in interactive panel discussions
3. Discuss potential terms of reference for follow-on National Academies' study

January 29, 2013

0900 Welcome and Introductions
- Maj Gen (Ret.) Gerald Perryman, Jr., Independent Consultant

0905 Workshop Co-Champion Opening Remarks
- Maj Gen William Chambers, Assistant Chief of Staff for Strategic Deterrence and Nuclear Integration, Headquarters U.S. Air Force

0935 An Overview of Simple Decision Heuristics in Uncertain Environments
- Dr. Peter Todd, Professor, Department of Psychological and Brain Sciences, Indiana University

1050 Panel 1—Scenario-based Analytic Tools
- Lt Gen Robert Elder (USAF, Ret.), Research Professor, George Mason University
- Ms. Anne Russell, Director of Social Systems Analysis, SAIC

Moderator: Dr. Tony Cox, Cox Associates, LLC

1200 Continue Discussions *with lunch available*

1300 Panel 2—Leadership Profiling Approaches
- Dr. David Winter, Personality and Social Contexts Chair and Professor of Psychology, University of Michigan
- Dr. Stephen Walker, Professor Emeritus of Political Sciences, Arizona State University
- Dr. Margaret Hermann, Director, Moynihan Institute of Global Affairs, Syracuse University

Moderator: Dr. Jerrold Post, George Washington University

1515 Reaction to Day 1 Presentations
- All

1700 Adjourn

January 30, 2013

0900 Achieving a Politically and Technically Sustainable Nuclear Posture for the 21st Century
- Lt Gen (Ret.) Frank Klotz, Senior Fellow for Strategic Studies and Arms Control, Council on Foreign Relations

1015 Underlying Analyses for USSTRATCOM Force Structure
- Mr. Patrick McKenna, Chief, Plans Evaluation and Research Division, USSTRATCOM

1115 Congressional Perspectives on U.S. Strategic Deterrence
- Ms. Amy Woolf, Specialist in Nuclear Weapons Policy, Congressional Research Service

1215 Recent Studies and Analyses *with lunch available*
- Maj Justin Sorice, Air Force Office of Studies and Analyses, Assessments and Lessons Learned

1315 Panel 3—Threat Anticipation and Intelligence Analysis
- Dr. David Hamon, Principal, National and International Security Strategies, Analytic Services, Inc.
- Dr. Rich Wagner, Jr., Emeritus Technical Staff, Los Alamos National Laboratory

Moderator: Dr. Mike Wheeler, Institute for Defense Analyses

1530 Reaction to Day 2 Presentations
- All

1700 Adjourn

January 31, 2013

0900 General Discussion of Potential TOR for Follow-on Consensus Study
- All

1015 Snapshot of Workshop Committee Feedback from Day 1 and Day 2
- Mr. Norm Haller, Rapporteur

1115 Capstone Remarks: Strategic Deterrence Capabilities for the 21st Century Security Environment
- Gen Larry Welch (USAF, Ret.), Trustee Emeritus and former President, Institute for Defense Analyses

1215 Continue Discussions *with lunch available*

1300 Adjourn

Appendix C

Workshop Participants

SESSION 1
SEPTEMBER 26-28, 2012
WASHINGTON, D.C.

Committee Members

Maj Gen Gerald F. Perryman, Jr. (USAF, Ret.), *Chair*
Dr. Rafael Alonso
Dr. Allison Astorino-Courtois
Dr. W. Peter Cherry (NAE)
Dr. Louis A. Cox, Jr. (NAE)
Dr. Paul K. Davis
Dr. Jerrold M. Post
Dr. Daryl G. Press
Dr. Brian Skyrms (NAS)
Dr. Michael O. Wheeler

National Research Council Staff

Mr. Terry Jaggers, *AFSB Director*
Mr. Carter Ford, *Program Officer*
Mr. Norman Haller, *Rapporteur*
Ms. Sarah Capote, *Research Associate*
Ms. Marguerite Schneider, *Administrative Coordinator*

Speakers[1]

Lt Gen James Kowalski, Commander, Air Force Global Strike Command (AFGSC), Barksdale Air Force Base, Louisiana

[1]Individual speakers were not asked to review the draft workshop summary.

Maj Gen Williams Chambers, Asistant Chief of Staff, Strategic Deterrence and Nuclear Integration, Headquarters, U.S. Air Force
Dr. Robert Axtell, Chair, Department of Computational Social Science, Center for Social Complexity, Krasnow Institute for Advanced Study, George Mason University
Dr. Elbridge Colby, Research Analyst
Dr. Diane DiEuliis, Deputy Director, Office of Policy and Planning, Office of the Assistant Secretary for Preparedness and Response, U.S. Department of Health and Human Services
Mr. Hunter Hustus, Technical Advisor, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
CAPT (Ret.) Gail Kilisch, Owner and Managing Principal, BTG Ventures, LLC
Mr. Orde Kittrie, Senior Fellow, Foundation for Defense of Democracies, Professor of Law, Sandra Day O'Connor College of Law, Arizona State University
Mr. Patrick McKenna, Chief, Plans Evaluation and Research Division, USSTRATCOM
Dr. David Palkki, Deputy Director, Conflict Records Research Center, National Defense University
Dr. Rita Parhad, Associate Partner, Monitor360
Dr. C. Paul Robinson, President Emeritus, Sandia National Laboratories
Dr. Barry Schneider, Retired Director, U.S. Air Force Counterproliferation Center

Guests

Dr. James Blackwell, Special Advisor, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
Mr. Scott Couture, Special Assistant to the Under Secretary, Of the Air Force for Nuclear Matters, SAF/US
Ms. Laurie Fenstermacher, Program Manager, ISR Socio-Cultural Analysis, 711th Human Performance Wing, Air Force Reserch Laboratory
Dr. Mark Gallagher, Technical Director, Air Force Office of Studies and Analyses, Assessments and Lessons Learned
Mr. Kevin Gluck, Senior Cognitive Scientist, Air Force Research Laboratory
Col. Duane Hiebsch, Chief, Strategy Division, AFGSC A8X
Maj Kevin Kippie, Chief of Nuclear Aircraft Employment, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
Mr. Jeff Larsen, Senior Scientist, SAIC
Dr. Djuana Lee, Program Element Monitor, Basic Reseearch, SAF/AQRS
Mr. Darphaus Mitchell, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
Dr. Edward Robbins, Supervisory Management Analyst, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
Maj Kyle Smet, Nuclear Policy and Integration, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
Dr. Janet Sutton, Senior Research Psychologist, 711th Human Performance Wing, Air Force Research Laboratory
Dr. John Swegle, Senior Advisory Scientist, Savannah River National Laboratory

Dr. Victor Utgoff, Senior Division Fellow, Institute for Defense Analyses
Dr. John Valentine, Chief Scientist, SAIC
Dr. Ursula Wilder, Clinical Psychologist, CIA & DNI/National Counterterrorism Center
Maj Mark Wittig, Senior Technical Advisor, USSTRATCOM
Dr. Christopher Yeaw, Chief Scientist, AFGSC

SESSION 2
JANUARY 29-31, 2013
WASHINGTON, D.C.

Committee Members

Maj Gen Gerald F. Perryman, Jr. (USAF, Ret.), *Chair*
Dr. Rafael Alonso
Dr. Allison Astorino-Courtois
Dr. W. Peter Cherry (NAE)
Dr. Louis A. Cox, Jr. (NAE)
Dr. Paul K. Davis
Dr. Jerrold M. Post
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Speakers

Maj Gen William A. Chambers, Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration, Headquarters U.S. Air Force
Gen Larry D. Welch (USAF, Ret.), Trustee Emeritus and former President, Institute for Defense Analyses
Lt Gen Robert J. Elder (USAF, Ret.), Research Professor, George Mason University
Lt Gen Frank G. Klotz (USAF, Ret.), Senior Fellow for Strategic Studies and Arms Control, Council on Foreign Relations
Mr. David Hamon, Principal, National and International Security Strategies, Analytic Services, Inc.
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Maj Justin E. Sorice, Scientific Analyst, Air Force Office of Studies and Analyses, Assessments and Lessons Learned
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Dr. Rich Wagner, Jr., Emeritus Technical Staff, Los Alamos National Laboratory
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Mr. Kevin Gluck, Senior Cognitive Scientist, Air Force Research Laboratory
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Mr. Hunter Hustus, Technical Advisor, Office of the Assistant Chief of Staff of the Air Force for Strategic Deterrence and Nuclear Integration
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Zero-Sustainment Aircraft for the U.S. Air Force: A Workshop Summary

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A Workshop Summary

Gregory Eyring, Rapporteur

Committee on Zero-Sustainment Aircraft for the U.S. Air Force: A Workshop

Air Force Studies Board

Division on Engineering and Physical Sciences

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COMMITTEE ON ZERO-SUSTAINMENT AIRCRAFT FOR THE U.S. AIR FORCE: A WORKSHOP

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CLAUDE V. CHRISTIANSON, National Defense University
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AIR FORCE STUDIES BOARD

Preface

The Air Force recognizes that sustainment of legacy weapon systems is a strategic issue for the United States. To assist the Air Force in addressing this issue, the Air Force Studies Board of the National Research Council drafted terms of reference (TOR) in April 2012 for a short workshop to bring together Department of Defense organizations and industry to highlight current sustainment practices that the Air Force might leverage to reduce maintenance and sustainment costs in the near term. The National Research Council approved the TOR in July 2012. The 3-day workshop was then held on December 4-6, 2012, at the National Academy of Sciences Building in Washington, D.C.[1]

The committee is grateful for the support of the Air Force champion of this workshop, Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations, and Mission Support, Headquarters Air Force. Lt Gen Fedder articulated a set of clear desired outcomes for the workshop prior to the workshop and in person at the workshop. In addition, the committee thanks the many expert speakers and guests who contributed to this activity. Finally, the committee's role was limited to planning the workshop, and the workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop.

Claude M. Bolton, Jr., *Chair*
Committee on Zero-Sustainment Aircraft for the
U.S. Air Force: A Workshop

[1]This is the second in a series of workshops conducted by the Air Force Studies Board at the request of the U.S. Air Force. It follows an earlier workshop titled "Energy Reduction at U.S. Air Force Facilities Using Industrial Processes," held on November 5-7, 2012.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Claude V. Christianson, National Defense University,
Nancy G. Leveson, Massachusetts Institute of Technology,
Eli Reshotko, Case Western Reserve University, and
Raymond Valeika, Delta Airlines (retired).

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views presented at the workshop, nor did they see the final draft of the workshop summary before its release. The review of this workshop summary was overseen by Wesley L. Harris, Massachusetts Institute of Technology. Appointed by the NRC, he was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the author and the institution.

Contents

APPENDIXES

Acronyms

ACAT	acquisition category
AFLCMC	Air Force Life Cycle Management Center
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AFSAC	Air Force Security Assistance Center
AFMC	Army Force Materiel Command
AFSC	Air Force Sustainment Center
AIM	automotive information module
ALC	Air Logistics Complex
AMC	Air Mobility Command
APU	auxiliary power unit
BCA	business case analysis
CFLI	core function lead integrator
CLS	contractor logistics support
DAU	Defense Acquisition University
DLA	Defense Logistics Agency
DLR	depot-level repair
DoD	Department of Defense
E2E	end to end
ERP	enterprise resource planning
FY	fiscal year
ISR	intelligence, surveillance, and reconnaissance
KPP	key performance parameter
KSA	key system attribute
LCC	life cycle cost
LHA	Logistics Health Assessment

LO	low observable
MAJCOM	major command
NAVAIR	naval aviation
NRC	National Research Council
OCO	overseas contingency operations
OEM	original equipment manufacturer
P&W	Pratt and Whitney
PEO	Program Executive Office
PM	program manager
PSI	product support integrator
PSM	program support manager
R&D	research and development
S&T	science and technology
TOR	terms of reference
VEMSO	Vehicle and Equipment Management Support Office
WSS	weapon system sustainment

Overview

Overall Air Force weapon system sustainment (WSS) costs are growing at more than 4 percent per year, while budgets have remained essentially flat. The cost growth is due partly to aging of the aircraft fleet and partly to the cost of supporting higher-performance aircraft and new capabilities provided by more complex and sophisticated systems, such as the latest intelligence, surveillance, and reconnaissance platforms. Furthermore, the expectation for the foreseeable future is that sustainment budgets are likely to decrease so that the gap between budgets and sustainment needs will likely continue to grow wider. Most observers accept that the Air Force will have to adopt new approaches to WSS if it is going to address this problem and remain capable of carrying out its missions.

In this context, the original intent of this 3-day workshop was to focus on ways that science and technology (S&T) could help the Air Force reduce sustainment costs. However, as the workshop evolved, the discussions focused more and more on Air Force leadership, management authority, and culture as the more critical factors that need to change in order to solve sustainment problems. Many participants who spoke at the workshop commented that while S&T investments could certainly help—particularly if applied in the early stages ("to the left") of the product life cycle—what is also important is adopting a transformational management approach—down to the shop level—that defines the user-driven goals of the enterprise, empowers people to achieve them, and holds them accountable. Several workshop participants urged Air Force leaders to start the process now, even though it will take years to percolate down through the entire organization. These sustainment concerns are not new and have been studied extensively, including in recent reports from the National Research Council's Air Force Studies Board and the Air Force Scientific Advisory Board.[1,2]

[1]NRC. 2011. *Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet These Needs*. Washington, D.C.: The National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=13177.

[2]Air Force Scientific Advisory Board. 2011. *Sustaining Air Force Aging Aircraft into the 21st Century*. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA562696. Last accessed December 27, 2012.

POSSIBLE ACTION ITEMS FOR AIR FORCE CONSIDERATION

Box O-1 contains potential actions that could be implemented within 6 months, which were suggested by various workshop participants to enable the Air Force to begin to address its ever-increasing sustainment costs.

BOX O-1 Possible Action Items Suggested by One Workshop Participant for Air Force Consideration

A. Initiate a sustainment pilot project, championed by the Air Force chief of staff and led by the Air Force Materiel Command commander, partnering with another Major Command, using the Navy's NAVAIR sustainment program as a template to:[1]

1. Manage Air Force weapon system sustainment (WSS) as an integrated enterprise that cuts across program boundaries.
2. Define a user-driven outcome the Air Force intends to achieve for the selected system, and describe the high-level supporting metrics that will be used to measure progress toward this outcome.
3. Decide who is the single individual or office responsible for managing Air Force WSS costs.
4. Define a simple, standard tool to use for a system's sustainment business case analysis that includes visibility over all actual sustainment costs incurred.
5. Establish or enhance transparency of total sustainment costs across the system's life cycle as well as across all Air Force sustainment and operational organizations.

B. Utilize the CORONA conference[2] mechanism to reach agreement among 4-star process owners as to the outcome metric to be used for the pilot program.

[1]The transformation of the Naval Aviation Enterprise went well beyond solely the application of "Lean" principles and into wide-ranging organizational and cultural changes.

[2]CORONA conferences are held three times a year allowing the secretary of the Air Force, the chief of staff, and senior Air Force military leaders to come together for open discussions on issues relevant to the Air Force's future.

1

Introduction

Each year, the Air Force faces a growing gap between the sustainment needs of its weapons and its annual sustainment budget. Overall weapon system sustainment (WSS) costs are growing at more than 4 percent per year while budgets have remained essentially flat. The cost growth is due in part to aging of an aircraft fleet (the average age is 23 years) that is suffering from increasing corrosion and fatigue cracking, with the attendant difficulty of finding replacement parts that are no longer in production and software written in languages that are no longer used. Costs are also rising due to the need to support higher-performance aircraft and new capabilities provided by more complex and sophisticated systems, such as the latest intelligence, surveillance, and reconnaissance (ISR) platforms. Furthermore, the expectation for the foreseeable future is that sustainment budgets are likely to decrease, so that the gap between budgets and sustainment needs will likely continue to grow wider. One workshop presenter suggested that the cost of ownership may be more threatening to aircraft than the enemy. Several participants noted that the Air Force will have to adopt new approaches to WSS if it is going to address this problem and remain capable of carrying out its missions.

These sustainment concerns are not new. The issue has been extensively studied, including in recent studies by the Air Force Studies Board of the National Research Council (NRC) and the Air Force Scientific Advisory Board.[1,2] There is recognition that part of the answer lies in bringing consideration of a weapon system's entire life cycle into the early planning and design phases of the weapon's acquisition process. Design choices such as materials, fasteners, and so on can have a big impact on maintenance costs, and principles, such as modular design and quick disconnects between modules, can aid in reducing disassembly and replacement costs. Numerous recommendations have also been made that address the way the Air Force organizes and manages its sustainment efforts—with many suggesting that the Air Force should

[1]NRC. 2011. *Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet These Needs*. Washington, D.C.: The National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=13177.

[2]Air Force Scientific Advisory Board. 2011. *Sustaining Air Force Aging Aircraft into the 21st Century*. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA562696. Last accessed December 27, 2012.

manage sustainment as an integrated enterprise, rather than as a series of parallel efforts for the various weapons programs.

The Air Force has begun to take a more integrated view of sustainment through, for example, consolidating sustainment responsibilities within the Air Force Materiel Command (AFMC) and organizing itself around eight core functions, each with an individual designated as a core function lead integrator. It remains to be seen whether these organizational changes will help to break down barriers to a more integrated approach to sustainment, although several workshop participants commented that there were opportunities for positive change.

WORKSHOP TERMS OF REFERENCE

The terms of reference for this workshop are given in Box 1-1.

BOX 1-1 Terms of Reference

An ad hoc committee will plan and convene one 3-day public workshop to (1) discuss how science and technology can reduce aircraft sustainment costs in the Air Force and (2) review costs in maintenance, upgrades, and aging aircraft in the Air Force.

The committee will develop the agenda for the workshop, select and invite speakers and discussants, and moderate the discussions.

In organizing the workshop, the committee might also consider additional topics close to and in line with those mentioned above. The workshop will use a mix of individual presentations, panels, breakout discussions, and question-and-answer sessions to develop an understanding of the relevant issues. Key stakeholders will be identified and invited to participate. One individually authored workshop summary document will be prepared by a designated rapporteur.

WORKSHOP STRUCTURE, SCOPE, AND APPROACH

The 3-day workshop, which occurred on December 5-7, 2012, in Washington, D.C., consisted of a series of presentations by invited speakers (biosketches of the committee members are provided in Appendix A; the workshop agenda is provided in Appendix B), with each presentation followed by general discussion. Broadly, the first day was devoted to presentations by Air Force and Department of Defense academic personnel; the second day to presentations on experiences within the other services and industry contractors; and the final half-day to discussion among all participants.

The original intent of this workshop was to focus on how the Air Force's science and technology (S&T) dollars should be spent to reduce sustainment costs, as suggested by Task 1 in the terms of reference (Box 1-1). Indeed, the workshop participants did hear from representatives of the Air Force Research Laboratory on its S&T investments and from several presenters in the military services and in industry regarding cases in which technology insertion had saved sustainment dollars.

Chapter 2 of this report provides a summary of the presentations delivered at this workshop and of the discussion that followed. Chapter 3 summarizes the discussion that occurred on the last day, organized into the following five general topic areas: (1) leadership and management; (2) mission statement and metrics; (3) setting budget priorities and funding; (4) relationships with the contractor community; and (5) culture issues and training.

2

Presentations and Comments

The workshop participants heard a series of presentations on sustainment challenges and initiatives within the military services and in private sector companies representing the aircraft industry. Abstracts of these presentations are provided in Appendix D. A brief summary of the main points of the presentations and the ensuing discussion is given next, in chronological order of presentation.

TUESDAY, DECEMBER 4, 2012

Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters, U.S. Air Force

Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters, U.S. Air Force, is responsible for weapon system sustainment (WSS) for the Air Force. Lt Gen Fedder noted that the elements of life-cycle WSS costs are spares/consumables, manpower, sustaining support, and depot maintenance.[1] These costs can be put in four categories: depot purchased equipment maintenance (33 percent), contractor logistics support (CLS; 61 percent), technical orders (1 percent), and sustaining engineering (5 percent). WSS baseline funding with supplementals has been about 80 percent of current requirements, but future funding is expected to fall further and further behind requirements.

CLS costs are driving overall WSS cost growth; CLS is growing at 7.9 percent per year, compared with 4.3 percent per year for WSS generally. The recent emphasis on intelligence, surveillance, and reconnaissance (ISR) aircraft is one driver, since these are contractor-maintained. In general, sustainment of newer weapon systems tends to be more contractor-heavy. Speed in acquisition also tends to work against organic sustainment.[2] Lt Gen Fedder concluded by listing some initiatives to enhance sustainment cost management:

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[1] Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters, U.S. Air Force, “Air Force Studies Board Workshop: Zero-Sustainment Aircraft,” presentation to the workshop on December 5, 2012.

[2] For the purposes of this workshop summary “organic sustainment” is defined in the following way: “Organic logistics infrastructure refers to U.S. government entities (principally DoD organizations) such as inventory control

- Strategy guidance/tools/governance to life-cycle management community for building affordable/effective product support strategies;
- Enterprise-level initiatives such as NextGen CLS; and
- Individual program initiatives, including sustainment partnerships.[3]

Following the presentation, one observer noted that the F-22 was supposed to need only one-half of the maintenance required by the F-15 and asked, what happened? According to Lt Gen Fedder, the F-22 was envisioned to not need low observable maintenance specialists, just a "mech-tech" provided by the OEM. This turned out not to be the case. In addition, the Air Force added an egress system and other specialties and had to buy back the manpower to support these. There is a higher confidence that the F-35 will not need so many specialties, and this should result in large savings compared with the F-22.

Several participants raised critiques of the way the Air Force estimates the total costs of sustainment. One suggested a better breakdown of costs into five components that captures 95 percent of the costs: (1) maintenance, repair, and overhaul; (2) training; (3) personnel; (4) energy; and (5) modifications and upgrades. Because costs are incurred in so many different places, controlled by different authorities, rules, and colors of money, intelligent investment decisions cannot be made. A participant noted that the Air Force needs to view sustainment from a fleet perspective. The first question needs to be, What is the best way to deliver support? This participant offered as an example a similar situation in the Army. The M1 tank upgrade and fuel accounts were in different places, so when the question arose as to whether to put diesel in the tank, it was not possible to consider this from a business perspective. How can these components be brought together under one person?

Another participant remarked that data systems are not available that would serve as the basis for making smarter sustainment decisions. Knowing what people are actually doing is the key to cutting costs. Focusing on budgets is not the same as focusing on costs. Budgets reflect expenditures, not costs. The Air Force is budget-driven, but costs are more important. He noted that with respect to the growth of CLS costs, the Air Force dug itself a hole when it failed to purchase technical data at acquisition, which would have allowed the option to bring sustainment in-house. At the same time, the Air Force has lost technical expertise due to increase reliance on contractors, so the Air Force does not have access to what is driving CLS costs higher. On the organic side, this participant noted that another piece of the problem is that the supply chain and the depot are separate. "Which drives the bus?" The airlines have the same problem of knowing actual cost, but operationally the supply chain is under control of a

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points, maintenance depots, distribution warehouses, and transportation facilities. Like the garden variety organic farmer who uses only natural or self-produced products, organic infrastructure sustainment uses the government's ability to support a product's mechanical and structural demands, such as those seen by the C-17, over the course of its life." Albert Barnes and Capt Lewis Johnson, U.S. Air Force, Going Organic: The C-17 Depot Maintenance Activation Working Group, Defense *AT&L Magazine,* September-October, 2010. Available at http://www.dau.mil/pubscats/ATL%20Docs/Sep-Oct10/Barnes%20sept-oct10.pdf. Accessed January 15, 2013.

[3]Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters U.S. Air Force, "Air Force Studies Board Workshop: Zero-Sustainment Aircraft," presentation to the workshop on December 5, 2012.

single manager/user. The same participant stated that a recent analysis suggested that a typical time required to get an ordered part in the Air Force is 17 days.[4]

Another comment related to the organization of the Air Force, to the effect that the Air Force looks at problems through discrete views, or soda straws (e.g., AF/A1-A4), and cannot combine these views to link smart sustainment choices with acquisition decisions. The Air Force cannot get its arms around costs and, therefore, has no ability to influence the acquisition side. The Air Force cannot win the battle looking through these lenses. In Figure 2-1, for example, what are the options for cutting? Where can the Air Force cut to minimize risk? The answers are not clear. Yet, another participant asked rhetorically how much it costs to fly the F-15, all elements of cost together, fully burdened. The answer is that the Air Force does not know. The cost per flying hour may be known, but these data are not inclusive. The goal is to bring all of the communities together to agree on a metric. And if the Air Force has the data, does it have a decision mechanism to set priorities?

Another participant asked if the organic sustainment piece is going down as CLS goes up. He stressed that if the Air Force does outsourcing correctly, it needs to do it in a way that reduces internal staff levels to reduce costs. Related to that, he asked if the Air Force has a depot strategy. He answered his own question by commenting that Air Force should look at ISR and decide what skill set to keep in house, but that this strategy has not been developed. According to the participant, with platforms rushed to deployment during wartime, such as certain ISR platforms or the Army mine-resistant, ambush protected vehicle, DoD needs to plan up front for how these platforms will be brought into the regular sustainment system after the war is over.

A final topic of discussion related to the need to bring life cycle considerations into the acquisition process from the beginning. Lt Gen Fedder stated that the Air Force is well aware of the need to do better in this regard. One participant observed that the Air Force does not have the decision tools to make trade-offs early in the acquisition process. In the last 25 years, the division between acquisition and sustainment has gotten worse. In his view, program managers (PMs) should be fleet life-cycle managers and work closely with logistics experts. The Air Force currently does not have the authority, tools, or visibility to affect other parts of the product life cycle. This issue was recognized in the 1970s, but 40 years later has not been resolved.

Katherine Stevens, Director, Materials and Manufacturing Directorate and Capability Lead for Agile Combat Support, Air Force Research Laboratory

Katherine Stevens, Director, Materials and Manufacturing Directorate and Capability Lead for Agile Combat Support, Air Force Research Laboratory (AFRL), gave an overview of the AFRL's role in science and technology (S&T) for sustainment in the near term, mid-term, and far term. She also cited a number of examples of successful development and transition of sustainment technologies. Near-term activities address challenges in the maintenance of the current fleet, such as improved nondestructive inspection tools and expertise in support of the

[4]For a commercial airline of approximately 350 aircraft, cutting 1 day in the work-in-progress cycle—that is, from removal to repair to return to service—could save $7 million in inventory investment. This could be as simple as returning a failed part to a repair facility faster, cutting repair time, among other factors.

Air Force corrosion enterprise. Mid-term goals are to support “condition-based maintenance” in part by improving life prediction tools and sustainability models. Far-term goals include reducing sustainment costs by integration of data, models, and simulations throughout the life cycle.[5] When a physical aircraft arrives for maintenance, a digital model of the aircraft—specific to that tail number, including deviations from the nominal design—is intended to be delivered as well. The model is planned to continually reflect the current state of the actual aircraft.

Dr. Stevens believes the central reason behind increasing sustainment costs is the increasing age of the Air Force fleet; the average aircraft has been in service for 23 years. Problems associated with aging include fatigue cracking, corrosion, parts unavailability, material degradation, and wear. AFRL develops solutions to technology readiness level 6 and then hands them off to depots or program offices. Asked about where AFRL’s requests for S&T support come from, Dr. Stevens indicated that signals come from both major commands (MAJCOMs) and program offices on warfighter needs. Projects from the program offices tend to focus on specific problems. The core function master plans provide more general guidance, and the MAJCOMs provide sustainment technology plans. Dr. Stevens indicated that it is challenging to decide how to invest in S&T for long-term (25-year) payback. The fidelity of cost-benefit analysis is inconsistent. The Air Force does not have a base process to track return on investment. One participant noted that in fairness, the commercial aircraft industry does not do this very well either.

An important issue raised was that of whether there are appropriate incentives for reducing sustainment costs. Dr. Stevens noted that there is no incentive for a program office to, for instance, cut in half the replacement times for landing gear on the F-22 unless it is given a requirement. Sometimes there are contractor incentives for improvements, but these are rare. It would also be possible to incentivize organic depots to find innovative ways to reduce sustainment costs, but this is not currently part of the culture. She observed that contract structure is the key to providing incentives—for example, a fixed-cost contract with a 50/50 cost share of any documented savings. Cost-plus contracts do not provide these incentives. Dr. Stevens believes that current contracting practices hold back full industry participation in reducing sustainment costs.

One participant noted that it had been about 2 years since the publication of the NRC’s report on Air Force sustainment. It appeared to him from the presentation that big changes were happening at AFRL, but he questioned whether the sustainment budget at AFRL was still in the range of 5-8 percent of the overall budget. Dr. Stevens responded that in the past, AFRL focused exclusively on S&T research, but now sustainment is part of the mission. While it was true that many AFRL staff feel that it is more exciting to work on the cutting edge of technology, there are also AFRL people who are passionate about keeping the Air Force flying. This is a continuing challenge in AFRL culture.

In response to a question about whether there is duplication of effort between AFRL engineers and life-cycle engineers in the program offices, one participant felt that a bigger issue was retaining good life-cycle engineers in the program offices because they can receive higher

[5] Katherine Stevens, Director, Materials and Manufacturing Directorate and Capability Lead for Agile Combat Support, Air Force Research Laboratory, “USAF Science and Technology for Sustainment,” presentation to the workshop on December 4, 2012.

salaries in the private sector. A different participant noted that a key element of reducing maintenance costs is to be able to identify the part that needs to be replaced right away, rather than having to follow a fault isolation tree. This requires good data on current component performance. Comparisons with the commercial airlines are not fair because the airlines have much younger fleets, and most aircraft are still in production. This is a big advantage for maintenance and parts replacement.

A final comment relating to personnel was that, in years past, development planning tools existed with which the Air Force defined capability gaps in the next 20 years, and experts ran models and simulations on all weapon systems, which became the basis for the program objective memorandum submission to Congress. This all went away when Congress zeroed out funding. The funding has now been restored, but the experts have now retired.

Steven Brown, Professor, Defense Acquisition University

Steven Brown, a professor at Defense Acquisition University and a former Air Force crash investigator, began by observing that flight safety is a passion in the Air Force. In his view, the Air Force could solve its sustainment problems if it had the same passion. The key is to institutionalize progressive change. His presentation was organized around five key areas of sustainment: cost, performance, management, contracting, and training. In each area, he described the current state of affairs, recent innovations, and, finally, suggestions for institutionalizing these changes.[6]

He estimated that about 65 percent of total ownership cost of an aircraft is operating and support (O&S) cost. It is very difficult to get a handle on total cost because the Air Force does not have data on life-cycle cost (LCC). In the acquisition process, O&S cost is a key system attribute (KSA) and must be estimated to check a box, but there is no hardcore requirement pertaining to it (it is not a key performance parameter, or KPP), and it is not tracked. Dr. Brown remarked that acquisition and LCC are not connected in the Air Force. They are managed by two completely separate organizations at the system program offices (SPOs). He suggested that improved analysis and tracking of LCC could be made a requirement.

Some participants related two anecdotes about poor decisions that were made because of a failure to consider life-cycle costs up front. In the F-22, the decision was made not to carry a ladder on board in order to save weight. This necessitated every airfield to have deployable ladders on hand to serve the F-22s, at much higher cost. In another example, the Army proposed that the future combat system carry bottled water, since the cost of delivering water to the vehicles was so large. However, the cost of delivery was borne by a different office, and it proved impossible to make a business case for the vehicles to carry the extra weight. Some participants noted that the lesson drawn is that program offices must have the tools available to make the correct decisions where these kinds of life-cycle trade-offs are involved.

One participant agreed that if money is important, the Air Force has to track it in order to make proper decisions, and the Air Force has to have appropriate metrics. A common metric is dollars per flying hour, but that does not account for capability. The Air Force needs to know

[6]Steven Brown, Professor, Defense Acquisition University, “Institutionalizing Low Sustainment Aircraft,” presentation to the workshop on December 4, 2012.

what elements of cost are included in the estimates in order to compare with industry. In the airline industry, maintenance cost per available seat mile is the metric. Utilization is also key. In the airline industry, aircraft commonly fly 3,000-4,500 hours per year, much more than Air Force aircraft.

Dr. Brown suggested that the Air Force look outside for best practices to benchmark against. The Navy has been emphasizing "gate reviews" early in the acquisition process that have been demonstrated to reduce O&S cost uncertainty, and the Air Force could learn from this. Pratt and Whitney and others have developed useful cost models. Finally, other countries such as the United Kingdom and Canada realize lower sustainment costs because they have historically operated under tighter dollar constraints, and there are likely to be lessons to be learned there.

On the performance issue, Dr. Brown noted that system availability (measured as percent time available) is typically a KPP, while system reliability (measured in terms of mean time between failures) is often a lower level KSA. This was the case with the Joint Strike Fighter (JSF), where "mission reliability" (availability) was the KPP. He believes that this decision is one reason that the growth in system reliability of some versions of the JSF has lagged behind what was planned. One participant questioned what the availability metric really means. It is not clear in the field what the "fudge factors" are. At the strategic level, this is not a concern. Is the aircraft flying or not? But at the tactical level, it is likely that different metrics are being used for example, for aircraft moving through the depots. To institutionalize improvements to sustainment performance, Dr. Brown recommends establishing system requirements for reliability and maintainability.

On the management issue, DoD Instruction 5000 describes a systems engineering process for weapons programs in which the PM is also the "life-cycle systems manager," with no dedicated logistician in the loop. However, a new key leadership position of product support manager (PSM) has now been established for all acquisition category I and II (ACAT I and II) programs. This life-cycle logistician, who works directly for the PM, is OSD-certified at level 3 and is also supposed to be acquisition-certified. To institutionalize this advance, Dr. Brown recommended filling the PSM positions with highly qualified life-cycle logisticians and benchmarking sustainability readiness levels against maturity models in the other services, industry, and allied initiatives.

On the contracting issue, Dr. Brown noted the trend away from the PM being involved in the details of repairs, parts, and engineering toward a focus on performance-based logistics—availability, reliability, and mission effectiveness. The details of product support are increasingly being managed by product support integrators (PSIs) who work for the PSM. The PSIs are given contract incentives such as fees and 50/50 gain sharing as rewards for saving sustainment dollars. This strategy has been shown to work well for the F-117 and the F/A-18. The Defense Logistics Agency (DLA) has also initiated pilot programs that combine existing performance-based contracts for sustainment of common items (e.g., auxiliary power units (APUs), helicopter engines) managed by the different services into a single DoD contract. This enterprise approach to sustainment contracting is estimated to save about 20 percent on costs.

On the training issue, DoD is estimated to have nearly 17,000 life-cycle logisticians—some in the program offices, some in the supply chain, and some at the three Air Logistics

Complexes (ALCs)—94 percent of whom are civilians.[7,8] Defense Acquisition University (DAU) offers three levels of logistics certification and in 2013 will offer a new course in "business acumen" that will help acquisition personnel develop techniques for negotiating better business deals. In 2014, a senior seminar will be offered to current and selected PSMs that highlights the keys to PSM and PM success. A final comment following this talk was that DoD does not have the tools to measure return on investment or life-cycle cost, and instead of chief executive officers, chief financial officers, and quarterly reports, there is a political process that makes it hard to run sustainment in a businesslike manner.

James Yankel, Technical Director, Directorate of Logistics, Air Force Materiel Command

James Yankel, Technical Director, Directorate of Logistics, Air Force Materiel Command (AFMC), provided a perspective on sustaining aging aircraft from AFMC. Average growth of total aircraft sustainment costs is 6.5 percent per year, driven by increasing failure rates and maintenance man-hours associated with an aging fleet.[9] Funding is falling further and further behind WSS requirements. The biggest cost growth area is CLS. In the 1960s, the majority of sustainment was organic. Today, the majority is commercial contracts. In the future, the plan is to make sustainment more of a public-private partnership. Mr. Yankel described recent initiatives aimed at reducing sustainment costs and approaching sustainment more from an enterprise point of view. He explained that AFMC recently reorganized itself to achieve efficiencies by consolidating 12 centers down to the following 5:

- Air Force Research Laboratory (AFRL);
- Air Force Life Cycle Management Center (AFLCMC);
- Air Force Sustainment Center (AFSC);
- Air Force Test Center; and
- Air Force Nuclear Weapons Center.

In addition, processes for sustainment at AFMC are increasingly taking a life cycle and command-wide approach. These processes are undergoing performance reviews that

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[7]The number of DoD personnel who are responsible for life-cycle logistics, which is defined as "developing, fielding, and improving system sustainment," is large; however, this number is relatively small when compared to the number of people (~600,000) who are responsible for broader DoD logistics (Steven Brown, Defense Acquisition University, "Institutionalizing Low Sustainment Aircraft," presentation to the workshop on December 4, 2012).

[8]"The U.S. Air Force (USAF) currently has three Air Logistics Centers [Complexes] (ALCs), operating under the Air Force Materiel Command (AFMC), which provide acquisition, modification, and maintenance support for the Air Force aircraft fleets, end items, commodity parts, and some missile systems. The ALCs are complex, multi-faceted organizations. They provide support to the Air Force and other components of the Department of Defense (DoD) on numerous product lines." Excerpted from NRC, *Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet These Needs,* Washington, D.C.: The National Academies Press, 2011.

[9]James Yankel, Technical Director, Directorate of Logistics, Air Force Materiel Command, "Sustaining Aging Aircraft," presentation to the workshop on December 4, 2012.

emphasize standardized reporting across all weapon systems, requirements cost drivers, and technology insertion needs and opportunities.

Following the presentation, some participants raised questions about whether what is driving the cost of sustaining each weapon system is truly understood by the Air Force. The issue is not whether sustainment is accomplished by CLS or depot-level repair (DLR), but rather what is the best cost solution for the Air Force. Other participants pointed out that discussions of rising costs should consider operational tempo as a factor to determine if costs are reasonable. One participant opined that flight hours should be the common denominator, not average age. In the commercial airline industry, aircraft availability (or its opposite, downtime) based on the need for structural repairs is the cost driver, not repair cost.

A final topic of discussion was the AFMC reorganization and whether it is likely to produce the desired efficiencies. Some participants noted that this was an open question so soon after the reorganization, with the reorganization still in the "sausage-making" phase. Several observers saw a potential conflict between the responsibilities of the AFLCMC and the AFSC. There was sentiment expressed by some participants that there should be a strong cooperative relationship between the two centers and that the two complementary responsibilities should be clearly articulated and institutionalized to produce a common approach.

Joann Berrett, Director, Aerospace Sustainment Directorate, Air Force Sustainment Center

Joan Berrett, Director, Aerospace Sustainment Directorate, AFSC, began by stating that there is a high level of effort directed toward maintaining good communication between AFSC and AFLCMC. All elements of AFSC organic costs are being investigated, although she was not sure when the results would be available. The three major Air Logistics Complexes (ALCs)—Oklahoma City ALC; Warner Robins ALC; and Ogden ALC—are organized under AFSC.[10] She noted that the number of dollars needed to satisfy readiness requirements are projected to increase while the budget for WSS is expected to be flat from FY2012 to FY2018. AFSC's aim is to produce higher efficiencies through better processes and a higher level of integration. She cited some success stories in which average work flow days had been reduced through implementation of high-velocity manufacturing principles—for example, improved knowledge of an aircraft's condition before it arrives at the depot, and "gated production," in which all relevant repairs on an aircraft are completed before it can move on to the next gate.

Following this talk, there was a discussion of the Defense Logistics Agency's role. While some of DLA's successes were acknowledged by some participants—especially in the area of contracting, one participant claimed that it takes a very long time—17 days on average—to get an ordered part. Another observed that one reason is that the DLA does not own all the assets it needs—e.g., transportation—and that the Army's record is even worse. A final comment on DLA was that there is no integrated supply chain planning across the enterprise. DLA needs to be more agile and remove compartmentalization. Ms. Berrett was asked whether the "not invented here" syndrome still prevailed at the three ALCs. She answered that Lt Gen Litchfield

[10]Joan Berrett, Director, Aerospace Sustainment Directorate, Air Force Sustainment Center, "Driving to Cost Effective Readiness," presentation to the workshop on December 4, 2012.

had initiated a big push to standardize work processes and metrics at the ALCs, from the mechanic on the shop floor up to the senior managers.

Mike Jennings, Deputy Director of Logistics (Acting), Air Force Life Cycle Management Center

Mike Jennings, Deputy Director of Logistics (Acting), Air Force Life Cycle Management Center, described the makeup of AFLCMC, which focuses on acquisition and includes the program executive offices (PEOs). With the new five-center construct described above, Lt Gen C.D. Moore has more visibility across the enterprise, although no one person is empowered to execute an enterprise sustainment strategy. A Life Cycle Management Working Group was established that reviewed more than 160 processes and identified needs in the following six key areas owned by AFLCMC:

- *Develop human capital.* There is currently no standard training for specialties. There is now only a very limited capability to identify needed competencies and what AFLCMC now has, although there is an implementation plan for competency of the new PSM positions and other logisticians.
- *Developmental planning.* AFLCMC already possesses an “executive” role. This will be critical to having the ability to influence product support.
- *Product support business case analyses (BCAs).* Standard processes have been defined but, according to Mr. Jennings, still need oversight.
- *Repair sources.* Cross-program efficiencies need to be identified (for example, common radios on different platforms).
- *Centralized asset management and WSS prioritization.* Requirements standardization and justification are needed, as is a standard methodology for looking across platforms at engineering requirements.
- *Logistics health assessments (LHAs).* There is currently no ability to roll up sustainment data to the enterprise level; assessment and reporting are not lined up. A tool for milestone B to C exists (engineering and manufacturing development).[11]

The common thread among all of these needs is that there are many functional communities—engineering, budget, and so on—that need to work together. Processes need to be integrated—e.g., BCAs with depot source of repair. In Mr. Jennings’ view, Lt Gen Moore needs to have power over the product support enterprise, that is, influence over PEOs.

Mr. Jennings stated that the overall objective of AFLCMC is to provide affordable, effective product support. Metric number one is system availability, although the definition of availability is still under discussion. Affordability is judged by looking at the acquisition program baseline and comparing to actual expenditures. This will help in estimating future expenditures. Metric number two is LHAs, although he stressed that the Air Force must have the necessary data.

[11] Mike Jennings, Deputy Director of Logistics (Acting), Air Force Life Cycle Management Center, “Product Support Responsibilities and Cost Reduction Initiatives,” presentation to the workshop on December 4, 2012.

Mr. Jennings was asked who measures actual costs. He responded that currently the issue is not resolved and needs to be tied to firm data and updated when major events occur. This is still part of the "sausage making" at AFMC. A participant stressed that it is very important to check the BCA against actual costs. This need not be complicated, and it should not be necessary to clear the results with everyone unless there is a big deviation from forecasts. He noted that the fundamental challenge is to define an Air Force life-cycle cost model that will be used to plan and track costs. To be truly useful, it must be tied to budgets.

Final Thoughts—Day 1

Following this presentation, the chair asked for final thoughts from individual participants based on the presentations and discussions from the first day. The following individual views, which do not necessarily reflect the consensus of the workshop participants and speakers as a group, were expressed:

- Based on the positive discussion, it appears that the Air Force has the right leaders and the right people on the ground to address the sustainment problem. With regard to the aging fleet, the Air Force has not done a good job of going to the people who have worked these issues for three decades to learn lessons of how they have succeeded. In particular, the Air Force Security Assistance Center (AFSAC) supports more aircraft than are in the Air Force inventory. AFSAC's inventory includes WWII vintage aircraft all the way to the most modern aircraft. AFSAC has developed the expertise to mitigate a number of sustainment issues that the operational Air Force is facing. When asked whether or not AFSAC expertise had been tapped, the answer on three different occasions throughout the first day was no.
- The emphasis on standardization across the organization is positive. Implementing the "Lean" approach is not a short-term process—it is likely to take 8 years. The structural changes at AFMC are encouraging, but the Air Force lacks the right data and information to do a top-notch sustainment job. The challenge is all the more difficult with rotations of personnel.
- The problems caused by colors of money are discouraging and getting worse. They are also self-inflicted. This would be a good subject for further study.
- The discussion is reminiscent of the 1960s. The Air Force needs to track costs, and the life-cycle management effort should focus on a few low-hanging fruit. It needs a near-term success.
- The Air Force needs to define a life-cycle cost model for sustainment and disseminate it.
- There have been enormous changes in the past 2 years, and it appears that the recommendations of the NRC's sustainment report have been heard. However, continuity of leadership remains a problem. How can the Air Force institutionalize change?

WEDNESDAY, DECEMBER 5, 2012

Maj Mark Blumke, Deputy Chief, Mx Systems and Integration Branch, Directorate of Logistics, Air Mobility Command

Maj Mark Blumke, Deputy Chief, Mx Systems and Integration Branch, Directorate of Logistics, Air Mobility Command (AMC), reviewed AMC initiatives to reduce maintenance and sustainment costs.[12] He listed the top cross-cutting drivers, in order of effects on operational availability or non-mission-capable hours (these do not reflect direct labor hours, but instead are measured on a 24-hour clock). Engines appear second on the list, but in fact are the top cost driver. He stated that engine initiatives at AMC are driven by fuel-efficiency programs but also have the secondary effect of reducing sustainment costs. He presented several BCAs for engine upgrades in which the avoided maintenance costs were projected to yield savings on the same order as the fuel savings. However, one participant noted that no actual cost data was presented and stressed the importance of following up with actual data to compare with projected data. Furthermore, specific fuel consumption needs to be measured in a test cell, since a lot of extraneous factors come into play when trying to measure fuel consumption on a flying airplane. Another participant noted that constraints on the modifications budget were preventing cost-effective engine projects from going forward.

Another AMC effort that is intended to increase fuel efficiency and reduce maintenance is to reduce the use of APUs on aircraft when they are on the ground, since external generators are five times more efficient. One participant observed that putting clocks on APUs—and making them easy to read—would help in this effort. Maj Blumke went on to discuss structure-related initiatives at AMC, the most important of which is corrosion. He cited the 2010 report *Impact of Corrosion on Cost and Availability to DoD* that estimated that Air Force aviation and missile corrosion consumes 35 percent of maintenance costs, roughly $6.5 billion.[13] Many AMC aircraft are high on the list. Initiatives include funding development of corrosion prediction and growth models (particularly corrosion under paint) and sensors to monitor corrosion initiation and propagation. Corrosion is a serious issue, and AMC takes it seriously. AMC stands ready to work with other entities within the Air Force and DoD to advance corrosion prevention/control capabilities.

Many observers commented that if corrosion truly accounts for 35 percent of costs, it should be the object of a major cross-cutting S&T effort. Several noted that many studies by AFRL, the NRC, and others have already been done, and there was a funded program managed by the Joint Logistics Command to address corrosion across the Air Force. A participant questioned, What happened? One participant familiar with the effort said a lot of coatings were developed but that the initiative appeared to lose steam after awhile as ideas got used up.

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[12] Maj Mark Blumke, Deputy Chief, Mx Systems and Integration Branch, Directorate of Logistics, Air Mobility Command, "AMC Initiatives to Reduce Maintenance and Sustainment Cost Drivers," presentation to the workshop on December 5, 2012.

[13] Logistics Management Institute, 2010, *Impact of Corrosion on Cost and Availability to DoD.* Available at http://www.sae.org/events/dod/presentations/2012/impact_of_corrosion_on_cost_and_availability_to_dod.pdf. Accessed February 22, 2013.

A final comment on the presentation made three points. First, in the commercial airline industry, every time a panel is opened (e.g., during an inspection) the mechanic uses a basic corrosion protection spray. This has been in place for 15 years and should be routine. Does the Air Force have a comparable procedure? Second, if the Air Force is really focusing on cost to the enterprise, it should have a cost-related metric such as man-hours, as opposed to non-mission-capable hours. Third, the engine initiatives described appeared to be related to occasions on which major modifications were undertaken, but there was less emphasis on the smaller things that can be done. There are not that many modifications performed on old aircraft.

SMSgt Kevin Mead, Air Force Element Vehicle and Equipment Management Support Office

SMSgt Mead's organization is chartered to execute enterprise vehicle fleet management and sustainment for the Air Force. It is customer-focused at the base level and has authority to act without going through any MAJCOM. He described several initiatives that have saved man-hours and sustainment costs, including validating fleet requirements and rightsizing, utilizing a standard algorithm for budget forecasting, and introducing fleet health metric with an algorithm to measure the health and effective ages of the 97,000-vehicle fleet. The Vehicle and Equipment Management Support Office (VEMSO) has developed a fleet management decision support system with utilization criteria and validation processes. In addition, there is a program called automotive information module (AIM-2), to be completed by the end of FY2013, in which an installed module collects data on the vehicle usage characteristics, fuel type, etc., and transmits the information wirelessly to a worldwide database that is searchable by customers. This is enabling a condition-based maintenance approach.

The initiatives described in this presentation were praised in comments made by many participants who thought the fleet management perspective and the enterprise approach as refreshing. SMSgt Mead was asked if any other Air Force programs had come in to see the tools he was using. He responded that he had been visited by the construction and civil engineering communities and that tools are available on the community website. VEMSO reports directly to headquarters of the Air Force, which is very unusual.

One participant stressed that automated reporting of problems on ground vehicles is far in advance of the situation with aircraft. Aircraft need to be made "smart" so that they can tell engineers of any problems. Another observer said that the bigger problem is that everyone looks differently at metrics. The key metric is dollars for the enterprise. The best investment might be an anti-corrosion spray, not an engine modification. The PSMs recommend where to spend the next dollar in a particular program; the Air Force must create an environment where these recommendations can be made enterprise-wide. An example of the problem is the inability to change configuration and buy a new engine that would be better in all respects than doing a modification. In addition, the constraints associated with using specific funding areas are extremely burdensome. These funding rules are counterproductive to reducing sustainment and maintenance costs. A participant argued that the Air Force must empower fleet managers with the ability to expedite moving money from one area to another if the business case can be made.

Lt Col Brian Godfrey, Chief, Airborne Branch (A4CA), Air Combat Command Headquarters

Lt Col Brian Godfrey, Chief, Airborne Branch (A4CA), Air Combat Command Headquarters, gave an overview of sustainment from an Air Combat Command (ACC) perspective. The biggest cost drivers are structural cracks/corrosion, wing repairs/replacements, wiring faults, and low observable (LO) maintenance. These problems are exacerbated by fewer maintainers available, increasing operational tempo, and fleet aging. Sustainment cost successes include better fleet management—e.g., balancing the time spent by F-15s and F-16s in high- and low-corrosion environments— and shifting F-22 maintenance from contractor to organic. In his view, contractor logistical support is not a panacea. In the future, he believes S&T can be harnessed to save on maintenance in several ways: common/standardized testers; leveraging information technology (e.g., having mobile maintenance applications on a tablet carried by the mechanic to be able to troubleshoot, order parts, and close jobs at the aircraft); alternative fuels; and "cold spray" of metal onto surfaces to repair corrosion, cracks, and holes. Lt Col Godfrey was enthusiastic about the young, tech-savvy workforce at the depots and felt that they were an asset that could help implement new maintenance technologies.

One participant asked why the Air Force is still having problems with LO maintenance. Participants asked, Will the Air Force continue to have problems with the F-35? Did the Air Force learn the appropriate lessons from experience with the F-117 and the B-2 structures? The speaker remarked that one problem was that the Air Force did not have enough people then, and this is still true. Lt Col Godfrey was also asked whether he was proposing a standard test program. He responded that there had been such a program years ago that was a big failure. The lesson was to be careful of global information technology solutions. Another participant responded that the Air Force needs to define common data architectures across the enterprise, not common testers. The discussion then centered around enterprise resource planning (ERP) systems that are designed to improve business processes but are not designed specifically to enhance decision making. The data ERPs generate do enable better decisions, but the ERP itself is not a good decision-support tool. One participant noted that what would aid significantly in decision making would be an Air Force "app store" that would offer easy-to-use applications that would run off of the ERP, much like applications for today's smart phones.

Another comment was that the Air Force should make a business case for putting a "black box" on legacy aircraft, with sensors that tell where and when problems arise. The problem is how to fund this if it competes with funding for aircraft performance. A response by one participant was that there is money dedicated to the sustainment community that does not compete with performance—you just have to figure out where the money is. If corrosion is the most important problem, the Air Force needs to figure out how to put money against it. Who in the Air Force could make this decision? Program offices put out requirements for brochures on depot-level maintenance for that weapon system, but the Air Force does not have that at the corporate level. Centralized asset management just orchestrates the process program by program, but the Air Force is missing opportunities unless the Air Force looks across the board and implements changes broadly. Lt Col Godfrey offered that the core function lead integrator (CFLI) construct is one way to do this, but it is core function by core function, not enterprise wide. There is a disconnect between programs and the enterprise. In the commercial world, there is an FAA-approved manual that prescribes how to remove paint, and this is used for all products.

One participant remarked that LCMC should prescribe standards by which programs are managed—standard data elements that allow the Air Force to do what it needs to do. Another commented that LCMC should establish a task force on corrosion to synergize efforts; it might require 5 years to figure out how to do it, but the Air Force would know what it is spending on it. The Air Force can use information technology to streamline and customize tasks in such a way that users will inform the enterprise—the opposite of the traditional military chain of command. One observer noted that PMs are generally not in the life-cycle cost business. In the Army, through engine designs that took advantage of modules and quick disconnects, it would be possible to change out a Humvee engine in 2 hours instead of the current 32 hours, but who would pay for it? DoD needs to create a global supply chain; this is not just an Air Force problem. A final comment was that data mining is a powerful tool for figuring out where to position spare parts or services most efficiently. It was found, for example, that by mining data of people googling “cold and flu,” this was the best predictor of where flu vaccines should be sent.

BG Edward Dorman III, Director for Logistics Operations, Readiness, Force Integration and Strategy, Office of the Deputy Chief of Staff, G-4

BG Edward Dorman III, Director for Logistics Operations, Readiness, Force Integration and Strategy, Office of the Deputy Chief of Staff of the Army, G-4, addressed two topics: (1) operational energy consumption and (2) condition-based reset. Soldiers are using more fuel and battery energy than ever before, and energy drives operational capability—maneuver, awareness, communication, etc. The fully burdened cost of fuel ranges from $3.95/gallon to more than $56/gallon in Afghanistan. Batteries carried by soldiers are an important weight issue. The Army G4, chief of staff, and the secretary of the Army are leading a variety of initiatives to promote energy conservation and energy efficiency, including soldier-worn integrated power enhancement systems, wheeled vehicle systems to recharge batteries, and engine upgrades to improve efficiency. However, making soldiers more energy-aware requires training and changing the culture of senior non-commissioned officers and soldiers; the officers must not be the only ones to see the benefits.

Condition-based reset is an effort to get back to soldier maintenance in the field—toward organic unit-based as opposed to institution-based sustainment of equipment to save money. The examples given tended to focus on ground equipment rather than aviation. Condition-based reset has secondary impacts on reducing operational energy by reducing “tooth to tail” the entire logistics snake. One participant noted that sustainment solutions are not always materiel solutions; he liked the emphasis on gathering more information and the “condition-based” concept. Another participant stressed the importance of institutionalizing this approach, so that it would survive personnel rotations, and getting buy-in, down to the foxholes.

Joe Guenther, Vice President and General Manager, Evandale Turbofan and Turbojet Engines, General Electric Aviation

Joe Guenther, Vice President and General Manager, Evandale Turbofan and Turbojet Engines, General Electric Aviation, explained that factors driving engine sustainment costs are the operating environment, which is not under the warfighter control, the aircraft mission (for example, the decision to use the 4-engine B-2 bomber for close air support in Afghanistan), and thrust de-rate—only using full thrust when the airplane is full. Factors that can strongly affect maintenance costs are engine health monitoring, inspection practices, and regular engine washes. It is important to have the analytical capability to monitor engines that should come off the airplane today rather than fail in 3 weeks. If GE has a performance-based logistics contract, it monitors trends in engine health with electronic controls wirelessly. In fact, Mr. Guenther showed examples where sustainment managed by the original equipment manufacturer (OEM) resulted in lower cost per shop visit and longer time on wing. Engine fleet management is also important. The best engines are not needed for an easy route. One sees a lot of "tired" engines in the Air Force. As engines age, they become more expensive to restore.

New turbine engine technology will reduce fuel consumption and increase thrust-to-weight ratio. To take advantage of emerging capabilities, Mr. Guenther recommended continuing to expand the component improvement program, funding upgrades to the legacy fleet, re-engineering, and continuing investment in new technology/materiel. The discussion following this presentation was wide-ranging. Several observers related problems with the interpretation of existing regulations—e.g., what could be funded by 3400 (operations and maintenance) money versus 3010 (modifications) money. One participant opined that the challenge is to determine how sustainment translates into things that matter to the warfighters/operators. The platforms meet the mission but cost more dollars than they should. The participant commented that declining budgets should be viewed as opportunity to effect change. Another observer commented on the effects of the new CFLI construct on sustainment. Each quarter, "red" and "yellow" (non-combat ready) aircraft are reported up to the CFLI. One core function, agile combat support, represents 70 percent of the inventory, but the current process only addresses segments of the problem.

Raymond Valeika, Retired Senior Vice President for Technical Operations, Delta Airlines

Raymond Valeika, Retired Senior Vice President for Technical Operations, Delta Airlines, drew lessons from his management experience in the commercial airline industry for the Air Force. He explained that effective sustainment depends on transparent information, based on the following:

- *Manufacturers' data.* The relationship between the military and the OEMs is not as close as the relationship between the commercial airlines and the OEMs. There needs to be constant communication.

- *Operational data.* Having proper metrics is important. At Delta, the goal was to have no more than 12 aircraft undergoing unscheduled maintenance and 18 in scheduled maintenance out of a fleet of 600. These numbers were tracked daily.
- *Cost data.* It is critical to understand all elements of cost, including inventory, labor, aircraft downtime, overhead, and staff. Application of good sustainment management principles, such as focusing comprehensively on one aircraft at a time, saves money. Cost data also allow one to make trade-offs; e.g., one-engine taxi can save fuel but can hasten the failure of the other engine due to lack of warm-up time. *If saving money is the goal, it is critical to manage costs rather than manage budgets.*
- *Performance data.* One must understand and validate error rates. How many aircraft are out of service, and what does that mean? These data help determine training needs—typically 1 week per employee per year at Delta. Sick leave and absentee rates are key labor metrics that are tracked because they reflect employee attitudes toward work.

Mr. Valeika stated that transparent information drives organizational effectiveness. The organization must be integrated in order to capture the gains made by either operations or sustainment personnel. There has to be a place where authority comes together to resolve conflicts. The Air Force has a matrix structure that does not provide measures across the boundaries. For example, the user of a part is not responsible for having the part delivered. Cost is looked at in stovepipes. Landing gear on the F-15s were taken from spares and put on operational aircraft, leaving a field full of aircraft with no feet. This was done to get the mission accomplished, but at what cost?

Following this presentation, one observer noted that Gen Wolfenbarger, head of AFMC, is seeking an enterprise viewpoint of all centers in order to be able to tell the chief of staff what is going on. The three ALCs were once commanded by two-star flag officers and saw one another as competitors. With the recent reorganization, they now all report to Lt Gen Bruce Litchfield, commander of AFSC, who now has more clout, budget, and access. In this observer’s view, this is a big opportunity.

Mark Buongiorno, Director, Military Engine Aftermarket Business Development, Pratt and Whitney

Mark Buongiorno, Director, Military Engine Aftermarket Business Development, Pratt and Whitney (P&W), reviewed life cycle cost management practices at P&W. He noted that engine design largely determines sustainment requirements. In terms of the life cycle, he estimated that development is 11 percent of the cost, production 23 percent, and sustainment 66 percent. Cost drivers change over the life cycle, with depot-level repair being about 30 percent of 5-year recurring costs but nearly 75 percent of 50-year recurring costs. He stressed that active life-cycle management is required in all program phases and cited examples of cases where P&W’s approach had saved the Air Force money. P&W works with the depots to determine when engines get overhauled. It presents metrics and cost drivers to the operators—a very rich data exchange. Finally, P&W has an investment program to continuously improve its products through technology insertion. Following this talk, one observer commented on the differences between military and commercial aircraft engine utilization. Military aircraft are flown much differently than commercial aircraft, leading to shorter engine life on the military side. Effective sustainment requires a serial-number-specific sustainment work program.

Final Thoughts—Day 2

Following this presentation, the chair asked for final thoughts from individual participants based on the presentations and discussions from the first day. The following individual views, which do not necessarily reflect the consensus of the workshop participants and speakers as a group, were expressed:

- There is a perceived deterioration in relationships between industry contractors and government acquisition personnel compared to the past. This theme recurred several times during the workshop.
- Depots have developed clever workarounds when they encounter problems with the system. These lessons should be captured.
- The Air Force does not have a simple answer to the question of what its mission is. The Navy, on the other hand, knows. The Air Force corporate structure is now organized around core functions, but the CFLI process has not been internalized yet.
- Color of money is a major issue.
- A process is lacking for converting cost-saving opportunities into a business case. The resources may be available if the business case is made.
- The Air Force does not have a meaningful cost tool to translate sustainment issues into the budget framework. It does not have to be complex and should begin with “small c” cost.

THURSDAY, DECEMBER 6, 2012

VADM Walter Massenburg (USN, Ret.), Senior Director, Mission Assurance Business Execution, Raytheon Company

VADM Walter Massenburg (USN, Ret.), Senior Director, Mission Assurance Business Execution, Raytheon Company, recounted a situation in naval aviation in the 1999-2001 period in which aviation depot-level repairable (AVDLR) costs were rising by double digits each year, and spare aircraft were being cannibalized to support deployed aircraft. Only 30 percent of the fleet was flyable. Appalled by this situation, the chief of naval operations (ADM Clark at that time) instituted an enterprise vision of naval aviation on a cross-functional, cross-organizational behavior model aligned to the “greater good.” The model used was a commercial one, with a chief executive officer, a chief operating officer, and a chief financial officer managing the aircraft fleet according to Lean management principles.

In the beginning, the Navy had no clue as to what was driving their costs. Strong egos were trying to protect individual programs. There was a culture oriented toward consumption; e.g., the metric being used on carriers was the number of arrested landings in a given time period. It took 4 years to break through the stovepipes and get rid of impediments, and they began to look at readiness differently. There was a single process owner (keeper of the metric). The metric adopted was "aviation units ready for tasking based on missions completed." This overall metric has a number of supporting metrics involving inventory, reliability, cycle time reduction, and total cost (all dollars/all financial stovepipes). Consistent with Lean principles, the goal is to achieve the metrics and no more. It is important to decide how much is enough; going beyond is not necessarily good and may be costly in both financial and personnel terms. The metric must be aligned with end-user value. One must (1) understand the outcome to be achieved, (2) define processes to achieve the outcome, and (3) reorganize only to the extent it affects the outcome.

VADM Massenburg cited a number of examples where this enterprise approach resulted in better fleet readiness at lower cost. Managers had to subordinate personal priorities for the greater good. Money left over at the end of the fiscal year was returned to the enterprise rather than spent. NAVAIR became the only organization recapitalizing its force, to the tune of $4 billion per year. This represented a "life spiral" rather than a death spiral. Much of the latter part of the presentation was devoted to encouraging productivity in the workforce. People are the source of capability to perform the mission and to achieve program success. It is the role of leadership to get the incentives right and inspire people. The culture should emphasize subordination to the metric, not collaboration per se. Work needs to be driven by demand pull, and worker talents need to be matched to the tasks. By emphasizing productivity, staff costs can be reduced without threatening the delivery of end products. VADM Massenburg concluded with a list of best practices and behaviors:

- Identify domains and assign single process owners.
- Assemble the right enterprise teams and gain commitment.
- Operate in support of a single fleet-driven metric (what the enterprise values).
  —Get agreement on scope, outputs, and linked metrics;
  —Make data transparent to promote trust and monitor performance;
  —Share knowledge on issues and key problems affecting the domain;
  —Recognize, nurture, and support technical authority; and
  —Identify entitlements (what's needed, when, and how much and no more).
- Agree on the desired output (e.g., readiness over cost), with focus on the trade space involving current and future readiness.
- Operate with discipline, governance, and a regular (timely) "drumbeat."
- Baseline every dollar, all the people, all the stuff, and all the capability within the domain, with assigned accountability for outcomes.
- Establish entitlements. Continually measure gaps to entitlement.
- Remove barriers to productivity.[14]

[14]Two books were recommended for further discussion of these principles: Gary Connors' *Lean Manufacturing for the Small Shop* (Society of Manufacturing, 2001) and Joel Levitt's *Lean Maintenance* (Industrial Press, 2008).

3

Wrap-Up Discussion

The final day was devoted primarily to general discussion and an attempt to distill the main points that had been presented by those who spoke at the workshop. The discussion involved the following topic areas: (1) leadership and management; (2) mission statement and metrics; (3) setting budget priorities and funding; (4) relationships with the contractor community; and (5) culture issues and training.

LEADERSHIP AND MANAGEMENT

Some workshop participants noted that the Air Force has recognized that the trend of year-over-year increases in sustainment costs cannot continue, especially with the prospect of budget reductions throughout DoD as the United States attempts to get its fiscal house in order. One participant asserted that unless the approach to sustainment changes, this will lead to a "death spiral" for the Air Force. However, another participant noted that the discipline of the anticipated budget cuts could be viewed as an opportunity to make fundamental changes in the Air Force's approach to sustainment.

Several questioned, however, whether there was leadership buy-in at the highest levels of the Air Force. Many observed that enterprise-level thinking does not occur in the Air Force. Some participants noted that policies must be articulated by the Air Force chief of staff and be internalized down to the wing level.

Echoing the conclusions of a previous study, several workshop participants noted that there is no single person responsible for sustainment throughout the Air Force.[1] Rather, sustainment decisions are made within the individual program "stovepipes," with no one having visibility across programs. One example cited was the issue of corrosion of parts and structures, which has been estimated to be responsible for up to 30 percent of sustainment costs across the Air Force. Each program wrestles with its own corrosion problems individually, whereas such a large, common problem would be better addressed holistically at the enterprise

[1] NRC. 2011. *Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet These Needs*. Washington, D.C.: The National Academies Press. Available at http://www.nap.edu/catalog.php?record_id=13177.

level. In the commercial airline industry, for example, there are policies in place that address the minimization of corrosion across all types of aircraft in the fleet.

The recent reorganization within AFMC with the consolidation of 12 product centers down to 5 was seen by some who spoke at the workshop as an opportunity for taking a more holistic approach to sustainment. The leader of the new AFLCMC, for example, deals with all program stovepipes and, in principle, has the ability to influence (although not to make) sustainment decisions across programs. Similarly, the leader of AFSC has control of the workflow at maintenance depots and test centers. Some participants pointed out that a challenge for AFMC is to determine what it is trying to achieve as an outcome and to get all of its components to work together to achieve that outcome. While the reorganization within AFMC was noted as a positive development by some workshop participants, it was not seen as a panacea. Indeed, reorganization per se was not seen as the solution to sustainment issues across the Air Force. Rather, a key point made by the some workshop participants involved the need to articulate at the highest levels the user-driven enterprise outcome desired and the need to give key individuals the authority and accountability for achieving that outcome.

Some workshop participants noted that the success achieved in NAVAIR, which was driven primarily by customer-focused metrics tied to fully burdened costs and through the application of “Lean” management principles, provides an “existence proof” and template for what can be accomplished in the Air Force. However, participants who commented did not minimize the challenges involved in implementing these management principles. They noted that the NAVAIR example was not implemented across the Navy as a whole, but only within a specific part. Accordingly, some participants expressed the view that implementation within the Air Force should start with a pilot or prototype project focusing on one weapon system (e.g., C-130 or F-15) and involving AFMC working with another MAJCOM, though there was disagreement about which one would make the best partner. Some workshop participants stated that AMC would be the most appropriate partner given its combat support mission, which is similar to that of AFMC. Others felt that Air Combat Command (ACC) would be the right choice, given the importance of getting the operators involved.

There was also discussion of who might champion such a pilot program. By analogy with the chief of naval operations’ role in the NAVAIR example, some participants who commented felt that the champion should be the Air Force chief of staff. However, it was noted that there needs to be another individual authorized to be the “campaign manager” who would facilitate training and changing peoples’ behavior. Some participants suggested that this person should be a four-star general, perhaps the leader of AFMC. The chief would give this individual the goal and associated metrics and hold him or her accountable for achieving them. It was pointed out that the transformation that took place at NAVAIR was difficult and took place over a period of at least 4 years. Thus, the continuity of leadership is a critical issue. A participant noted that regular rotations of command personnel make it imperative that changes be institutionalized so that they do not depend on individuals who may only be in the job for 18 months.

MISSION STATEMENT AND METRICS

A central tenet of Lean is that the entire organization needs to focus on what creates value for the end customer, and the use of resources for any other goal is a waste. Implicit in this formulation is that sufficient effort should be expended to preserve customer value, but no more. Continuing with the Lean theme, the overall goal needs to be supported by high-level metrics that are tied to the end user—in the Air Force case, the person who pulls the trigger. These metrics need not be complicated. One participant noted that in the commercial airline industry he focused every day on three metrics: (1) safety; (2) regulatory compliance; and (3) basic operational numbers, such as number of aircraft out of service. Throughout the workshop, examples were given of Air Force metrics that reflect consumption of resources (e.g., number of sorties or flight hours), with the implicit assumption that more consumption is better, rather than focusing on value for the mission or the end user. The focus is more often on output than outcome. In the NAVAIR example, the metric became “aircraft ready for tasking based on missions completed.” This metric, which evolved over time, focused not just on the readiness of aircraft flying missions at a given time, but also on the number available for training and for future missions. It thus minimized the practice of cannibalizing inactive aircraft in order to keep deployed aircraft flying. Finally, several participants noted that metrics need to be established for comptrollers that go beyond dollars obligated.[2]

SETTING BUDGET PRIORITIES AND FUNDING

One consequence of the program-oriented, stovepiped structure of the Air Force is the inability to set budget priorities based on cost to the enterprise as a whole; i.e., to answer the question, If the Air Force has only one additional dollar to spend, where should it be spent? The Air Force has no way of understanding and tracking total cost. The canonical example discussed at the workshop was the issue of corrosion. If, indeed, corrosion accounts for 30 percent of the Air Force sustainment budget, as some studies have suggested, a strong case can be made that the next dollar should be spent on a program to address it. With respect to sustainment, there is no mechanism for looking at budgets across programs, and, indeed, AFMC does not have visibility into ACC’s sustainment budget. During the workshop, it was noted that a number of budget metrics are being tracked because of legislative or other requirements, such as non-mission-capable hours and contractor logistics support, but it was pointed out that these are irrelevant to the question of how best to reduce total sustainment cost to the Air Force. Some participants expressed that a broader view of costs is required to encompass costs to accomplish the mission of the joint force and total sustainment cost.

One concern expressed by a workshop participant related to the fragmented approach to costs in the Air Force is the difficulty of translating legitimate needs into a convincing business case for funding. One participant expressed the need for a standard tool for doing this, stressing that it would be only a tool and need not be complicated. An important corollary is the need to track actual costs and compare them with projected costs to verify that the

[2]The transformation of the Naval Aviation Enterprise went well beyond solely the application of Lean principals and into wide ranging organizational and cultural changes.

projected gains are in fact realized. While several presenters showed projected cost savings associated with specific sustainment programs, there were little data presented on actual costs incurred.

Finally, some participants expressed the view that restrictions on how money can be spent from the various accounts associated with sustainment ("color of money") were a barrier to reducing total sustainment costs. For example, in the case of substituting a new part for an old part, if a new part has the same form, fit, and function as the old part, the substitute can be funded from the operations and maintenance account; if not, it is considered a modification, and must be funded from the acquisitions and modifications account. A case was cited in which an internal engine part that would improve performance was proposed to replace an older part. However, substitution of the new part could not be funded because it did not have exactly the same form, fit, and function as the old part and was, therefore, considered to be a modification, even though the outside profile of the engine remained the same.

RELATIONSHIPS WITH THE CONTRACTOR COMMUNITY

Although it was not a major theme of the workshop, a company representative raised a "red flag" regarding what he perceived to be deteriorating relationships between government managers and the contractor community and what this could mean to Air Force sustainment in the future. This participant noted that it is difficult to get a feel for the Air Force contracting process, due in part to the distributed authority. He stated that many companies having both commercial and government businesses are rethinking their involvement with the government because of all of the audits and red tape they have to deal with. He cited one case in which a government request for information had to be changed because small businesses could not compete. In the past, he asserted that communications between the Air Force and industry were much better than today. Government personnel used to be mentored on how to work with industry, but in his view this has all gone away.

This situation contrasts sharply with the strong relationships that exist between his company and its suppliers in the commercial world. All are working together to improve safety and compliance, and it is rarely necessary to negotiate contracts to improve an engine. There is much more freedom to act. As a result, this company much prefers working with other companies and is having difficulty staffing positions relating to military programs. There are no engineers waiting "pencils in hand" to contribute. In his view, the warfighters are getting less. While the evidence provided by this participant was anecdotal, the passion with which these views were expressed was notable.

CULTURE ISSUES AND TRAINING

According to one participant with experience in the NAVAIR Lean management experiment, the biggest barrier to changing Air Force culture and breaking through the stovepiped organization is likely to be the egos of the managers involved. The current incentives reward the best stovepipe, except during wartime. He argued that to adopt Lean management, the culture will have to change—subordination to the goal of the enterprise rather than pursuit of personal priorities. The objective should be to manage costs, not budgets. The “use it or lose it” mentality on budgets will have to be changed. It should be encouraged to return unspent money to the enterprise at the end of the fiscal year.

This participant asserted that Lean management also requires that all members of the organization understand the business and its objectives through training. In the Air Force case, this includes both warfighters and civilians. Various educational institutions were suggested as providers of this training, including the Air War College, although this would not be available to civilians. However, Lean management is not just to be pursued at the enterprise level. The same participant stressed that the goal should be to give every first line supervisor Lean management training. In his experience, Lean management works well on the shop floor, and in his business, it led to reductions in both overhead and paperwork. Another participant with a background in the Army testified that Lean management implementation tools and performance metrics are available and helped to facilitate Army policy updates and to rationalize supply regulations.

Appendix A

Biographical Sketches of Committee Members

Honorable Claude M. Bolton, Jr., *Chair*, became the executive-in-residence for the Defense Acquisition University (DAU) on January 3, 2008. Mr. Bolton's primary focus is assisting the DAU president achieve the congressional direction to recruit, retain, train and educate the Department of Defense (DoD) acquisition workforce. He is also a management consultant to defense and commercial companies and is a board member for several companies. Prior to becoming the DAU executive-in-residence, Mr. Bolton served as the assistant secretary of the army for acquisition, logistics and technology (ASAALT). As the ASA (ALT), he served as the army acquisition executive, the senior procurement executive, and the science advisor to the secretary. Mr. Bolton oversaw the Elimination of Chemical Weapons Program and had oversight and executive authority over the Project and Contracting Office charged with Iraq reconstruction. He was responsible for appointing, managing, and evaluating program executive officers as well as managing the Army Acquisition Corps and Army Acquisition Workforce. Mr. Bolton retired as a Major General in the U.S. Air Force following a highly decorated career. Some highlights of his Air Force service include serving as the commander of the Air Force Security Assistance Center, where he managed foreign military sales programs with totals exceeding $90 billion that supported more than 80 foreign countries; serving as a test pilot for the F-4, F-111, and F-16; program executive officer for the Air Force Fighter and Bomber programs; and the first program manager for the Advance Tactical Fighter Technologies program, which evolved into the F-22 System Program Office. An experienced command pilot flying more than 40 different aircraft including Army helicopters, during the Vietnam War he flew 232 combat missions, 40 over North Vietnam. Mr. Bolton served as commandant of the Defense Systems Management College and as inspector general and director of requirements at Air Force Materiel Command headquarters. Mr. Bolton's education includes a bachelor's degree in electrical engineering from the University of Nebraska, a master's degree in management from Troy State University; and an M.A. in national security and strategic studies from the Naval War College. In 2006, he was awarded a D.Sc. (Honoris Causa) from Cranfield University. In May, he was awarded an Honorary Doctor of Science degree from the University of Nebraska. Mr. Bolton is a member of the NRC's Air Force Studies Board and is a past member of the Committee on Evaluation of U.S. Air Force Preacquisition

Technology Development and Committee on Optimizing U.S. Air Force and Department of Defense Review of Air Force Acquisition Programs.

Claude V. Christianson is director of the Center for Joint and Strategic Logistics at National Defense University. Prior to this position he served as the Chief Executive Officer of Global Logistics Associates LLC, an Alexandria, VA-based, member-owned, limited liability company specializing in professional logistics and supply chain services. Mr. Christianson's military career culminated as the Director of Logistics, J4, on the Joint Staff. As the J4 he synchronized joint logistics support across all Services and DoD agencies in support of operations worldwide. As the Army's Deputy Chief of Staff for Logistics, G4, Mr. Christianson drove the fielding of a commercially sourced satellite network to the logistics domain, connecting logisticians across forward-deployed, austere environments. Mr. Christianson served as the Chief of Logistics, C4, Coalition Land Forces Command (CFLCC), during Operation Iraqi Freedom in Kuwait from 2002-2003, where he directed the planning and execution of logistics support for more than 240,000 ground forces and over more than 300,000 square miles. From 2000-2002, as the Deputy C4 (Logistics) for Combined Forces Command, U.S. Forces Korea Director of Logistics, J4, and Eighth U.S. Army Deputy Commanding General (Support), Mr. Christianson directed the planning and execution of logistics operations in support of all combined and joint forces in Korea. From 1998-2000, Mr. Christianson served as Deputy Commanding General, 21st Theater Support Command, European Theater Support Command in Germany where he coordinated the execution of European logistics support for Operation Joint Guardian (Kosovo). Mr. Christianson is a distinguished military graduate of the North Dakota State University Army ROTC program and holds a B.S. in industrial engineering.

Thom J. Hodgson is the James T. Ryan Distinguished University Professor, an Alumni Distinguished Research Professor, co-director of the Operations Research Program, and director of Graduate Programs of Engineering-On-Line at North Carolina State University (NCSU). He served as director of the Integrated Manufacturing Systems Engineering Institute at NCSU (1995-2011); director of the Division of Design and Manufacturing Systems at the National Science Foundation (1991-1993); head of the Industrial Engineering Department at NCSU (1983-1990); professor of Industrial and Systems Engineering at the University of Florida (1970-1983); operations research analyst at Ford Motor Company (1966-1970); and an officer in the U.S. Army (1961-1963). He is a member of the National Academy of Engineering and is a fellow of IIE and INFORMS and is the author or co-author of more than 80 journal articles and book chapters. Dr. Hodgson served as a member of the U.S. Army Science Board (1994-2000) and is a current member of the NRC's Committee on Energy Reduction at U.S. Air Force Facilities Using Industrial Processes: A Workshop.

Ronald Mutzelburg retired from the Boeing Company as the Washington, D.C. director for the Phantom Works and Advanced Systems. His organization managed the relationship with senior U.S. government technology and advanced systems customers, including the Defense Advanced Research Projects Agency, Office of the Director, Defense Research and Engineering, the Office of Naval Research, NASA (Aeronautics), as well as the Office of the Secretary of Defense, Joint Staff, and Military Service technology and long-range capability requirements offices. Prior to joining Boeing, Mr. Mutzelburg completed a 34-year government career within the DoD where he served in the following positions: deputy director for air warfare, Office of Strategic and Tactical Systems, Under Secretary of Defense for Acquisition, Technology and Logistics, where he was responsible for acquisition oversight for the B-1, B-2, C-17, F-22, F-18, Joint Strike Fighter, JSTARS, Unmanned Air Vehicles, several proprietary programs, and numerous air-to-air and air-to-ground weapons programs; assistant program director for the B-2, Aeronautical Systems Division (ASD), Air Force Systems Command; director of fighter propulsion, Propulsion Systems Program Office, ASD; director of Logistics, Propulsion Systems Program Office, ASD. From 1982 to 1983, Mr. Mutzelburg attended the National War College. From 1968-1982, he held numerous managerial and project officer assignments within Air Force Logistics Command. He has received numerous awards and much recognition over the years, including the DoD Distinguished Civilian Service Award (2001) and the Presidential Rank Award. He has an M.S. in industrial and systems engineering from Ohio State University and is a graduate of National War College. Mr. Mutzelburg was a member of the NRC’s Committee on Evaluation of U.S. Air Force Preacquisition Technology Development.

Lyle H. Schwartz retired from government service in 2004 after 18 years as a member of the Senior Executive Service. In his last position, as director, Air Force Office of Scientific Research (AFOSR), he guided the management of the entire basic research investment for the Air Force. He led a staff of more than 200 scientists, engineers, and support staff in Arlington, Virginia, and two foreign technology offices in London and Tokyo. As director he was charged with maintaining the technological superiority of the Air Force. Prior to becoming AFOSR's director, Dr. Schwartz directed the AFOSR's Aerospace and Materials Sciences Directorate. He is known for contributions to phase transitions in iron alloys, applications of Mossbauer spectroscopy, x-ray and neutron diffraction, characterization of catalysts, and policy issues concerning materials science and engineering. He is a member of the National Academy of Engineering and has written more than 85 technical papers and is co-author of two textbooks in materials science and engineering. Dr. Schwartz is a past member of the NRC’s Air Force Studies Board and was member of the NRC’s Committee on Examination of the U.S. Air Force’s Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs.

Raymond Valeika is an independent consultant advising major companies in aviation matters. He is an internationally recognized aviation operations executive with more than 40 years of experience managing large airline maintenance operations, equally comfortable in the United States and abroad dealing with regulators, manufacturers and employees. Mr. Valeika retired from Delta as senior vice president for technical operations where he directed a worldwide maintenance and engineering staff of more than 10,000 professionals, maintaining a fleet of nearly 600 aircraft. Through his leadership and focus on continuous improvement of the human processes in aviation maintenance, Delta Technical Operations consistently rated at the top of the industry for performance benchmarks in the areas of safety, quality, productivity, and reliability. He is currently is on the board of the Flight Safety Foundation as well as on the board of AerCap, Inc., and SRT. In addition, he was senior vice president of technical operations at Continental and vice president of maintenance and engineering at Pan AM. He graduated from St. Louis University with a degree in aeronautical engineering. Mr. Valeika has served on previous NRC studies sponsored by the Air Force, including the Committee on Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs and the Committee on Analysis of Air Force Engine Efficiency Improvement Options for Large Non-fighter Aircraft.

Appendix B

Workshop Agenda

OBJECTIVES

1. Address the current state of sustainment.
   a. What factors are responsible for driving your systems' sustainment costs? Where is our sustainment money going today?
   b. How do those cost factors change over time?
   c. Have you been successful in more effectively "managing" system sustainment costs?
2. Address the potential for science and technology to impact our future costs.
   a. What emerging technologies show promise to reduce or eliminate those sustainment cost drivers?
   b. How are you pursuing those opportunities? What "approaches" would you recommend to take advantage of emerging capabilities that might reduce our sustainment costs?

TUESDAY, DECEMBER 4, 2012

0900 Welcome and Introductions

- The Honorable Maj Gen (Ret.) Claude M. Bolton, Jr., Workshop Committee Chair

0930 Vision for the Workshop

- Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters U.S. Air Force

1000 Break

1015 Science and Technology for Sustainment

- Dr. Katherine Stevens, Director, Materials and Manufacturing Directorate, Air Force Research Laboratory

1115 Institutionalizing "Low Sustainment" Aircraft

- Dr. Steven Brown, Professor, Defense Acquisition University

1215 Continue Discussions *with Lunch Available*

1315 Air Force Materiel Command Initiatives

- *Aging Aircraft Maintenance*—Mr. James Yankel, Technical Director, Directorate of Logistics, Air Force Materiel Command
- *Driving to Cost-Effective Readiness*—Ms. Joann Berrett, Director, Aerospace Sustainment Directorate, Air Force Sustainment Center

1515 Break

1530 Air Force Materiel Command Initiatives Continued

- *Product Support Responsibilities and Cost Reduction Initiatives*—Mr. Mike Jennings, Deputy Director of Logistics (Acting), Air Force Life Cycle Management Center

1630 Workshop Committee Feedback to Day 1 Presentations

- All

1700 Adjourn

WEDNESDAY, DECEMBER 5, 2012

0900 Air Mobility Command Initiatives

- *Air Force Element (AFELM) Vehicle and Equipment Management Support Office (VEMSO) Initiatives to Reduce Sustainment Costs*—Maj Mark Blumke, Deputy Chief, Mx Systems and Integration Branch, Directorate of Logistics, Air Mobility Command

1000 Break

1015 Air Combat Command Initiatives

- Lt Col Brian Godfrey, Chief, Airborne Branch (A4CA), HQ Air Combat Command

1115 Army Initiatives

- *Informed Sustainment*—BG Edward Dorman III, Director for Logistics Operations, Readiness, Force Integration and Strategy, Office of the Deputy Chief of Staff, G-4

1215 Continue Discussions *with Lunch Available*

1315 Industry Initiatives Continued

- *GE Initiatives*—Mr. Joe Guenther, Vice President and General Manager, Evandale Turbofan and Turbojet Engines, General Electric Aviation
- *Sustainment: Managing Consequences of Failure with Transparent Information*—Mr. Raymond Valeika, Retired Senior Vice President for Technical Operations, Delta Airlines
- *Pratt and Whitney Initiatives*
  —Mr. Randy LaMar, Fleet Operations Discipline Chief, Pratt and Whitney
  —Mr. Mark Buongiorno, Director, Military Engine Aftermarket Business Development, Pratt and Whitney

1615 Workshop Committee Feedback to Day 2 Presentations

- All

1700 Adjourn

THURSDAY, DECEMBER 6, 2012

0900 Industry Initiatives Continued

- *The Enterprise Approach: Why Now?*—VADM Walter Massenburg (USN, Ret.), Senior Director, Mission Assurance Business Execution, Raytheon Company

1000 Break

1015 General Discussion with Participants to Include Next Steps

- All

1200 Continue Discussions *with Lunch Available*

1300 Adjourn

Appendix C

Workshop Participants

COMMITTEE MEMBERS

Honorable (Maj Gen [Ret.]) Claude M. Bolton, Jr., *Chair*
LTG (Ret.) Claude V. Christianson
Thom J. Hodgson (NAE)*
Ronald Mutzelburg
Lyle H. Schwartz (NAE)*
Raymond Valeika

NATIONAL RESEARCH COUNCIL STAFF

Terry Jaggers, Air Force Studies Board Director
Carter Ford, Program Officer
Greg Eyring, Rapporteur
Sarah Capote, Research Associate
Marguerite Schneider, Administrative Coordinator

SPEAKERS

Joann Berrett, Director, Aerospace Sustainment Directorate, Air Force Sustainment Center
Steven Brown, Professor, Defense Acquisition University
Mark Buongiorno, Director, Military Engine Aftermarket Business Development, Pratt and Whitney
BG Edward Dorman III, Director for Logistics Operations, Readiness, Force Integration and Strategy, Office of the Deputy Chief of Staff, G-4
Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters, U.S. Air Force
Lt Col Brian Godfrey, Chief, Airborne Branch (A4CA), HQ Air Combat Command

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*Member of the National Academy of Engineering.

Joe Guenther, Vice President and General Manager, Evendale Turbofan and Turbojet Engines, General Electric Aviation
Randy LaMar, Chief of Engine Logistics Program Management, Pratt and Whitney
VADM Walter Massenburg (USN, Ret.), Senior Director, Mission Assurance Business Execution, Raytheon Company
Katherine Stevens, Director, Materials and Manufacturing Directorate, Air Force Research Laboratory
James Yankel, Technical Director, Directorate of Logistics, Air Force Materiel Command

GUESTS

Joseph Baker, Deputy Capability Lead, Agile Combat Support, Air Force Research Laboratory/RX
Maj Michael Dunlavy, Air Force Materials and Manufacturing PEM, U.S. Air Force
David Madden, Division Chief, Product Support Engineering Division, Air Force Life Cycle Management Center, Air Force Materiel Command
Gary Reese, Director, Strategic Planning, Washington Operations, General Electric Aviation
Col Joe Robinson, Air Force/A4L
Cathy Snyder, Air Force Life Cycle Management Center
John Turco, General Electric Aviation
Angie Tymofichuk, Director, Engineering and Technical Management, Air Force Sustainment Center/EN
Marc Whitt, Senior Policy Analyst SAF/AQR

Appendix D

Presentation Abstracts

Speaker: Lt Gen Judith Fedder, Deputy Chief of Staff for Logistics, Installations and Mission Support, Headquarters U.S. Air Force

Presentation Title: A4/7 Sustainment

Multiple factors influence life-cycle costs: spares/consumables, manpower, sustaining support, fuel, depot Mx, other costs. Weapon system sustainment (WSS) is a key measure of component repair/overhaul; requirements are outpacing baseline funding, even with retirements. Air Force acquisition and sustainment communities are working to decrease these costs. Understanding sustainment factors and trade-offs early in the acquisition cycle is needed. Analysis of mission requirements, operational costs, life-cycle costs, reliability and speed of repairs, and using predictive maintenance tools and training is also necessary. Weighing contractor versus organic sustainment options and considering resources required for both the short- and long-term should be considered in this workshop. We are committed to evolving our logistics core competencies to posture logistics resources for the next fight and deliver cost-effective logistics readiness. Under the near term strategic priorities, we are committed to understanding and inform the cost of logistics and re-establishing expertise within life-cycle logistics. Considering resources to best meet readiness requirements effectively and efficiently is paramount, outlining the need for focused efforts.

Speaker: Katherine Stevens, Director, Materials and Manufacturing Directorate Air Force Research Laboratory

Presentation Title: Science and Technology for Sustainment

As the U.S. Air Force fleet continues to age, the cost of sustaining the fleet will consume an ever larger share of the Air Force budget. The Air Force Research Laboratory (AFRL) executes approximately $2 billion per year on science and technology efforts for the Air Force. A portion of these funds is directed towards sustainment, with an emphasis on keeping the current fleet safe, improving aircraft availability rates, reducing life-cycle costs (LCC) and improving the sustainability of future weapon systems. AFRL is executing an investment plan with near-, mid-, and far-term technology goals. Recent technology successes have resolved issues negatively impacting mission capable rates and resulted in multi-billion dollar LCC avoidance. Results of recent studies conducted by the National Academy of Sciences and the Air Force Scientific Advisory Board on the future of Air Force sustainment and how S&T is responding to the recommendations will be presented.

Speaker: Steve Brown, C.P.L., Defense Acquisition University

Presentation Title: Institutionalizing Low Sustainment Aircraft

During his presentation titled "Institutionalizing Low Sustainment Aircraft," Professor Steve Brown discussed five issues critical to successfully reducing sustainment of military air vehicles with the Air Force Studies Board at the National Academy of Sciences on December 4, 2012.

1. Sustainment cost requirements, data analysis, and reviews during the system life cycle;
2. RAM (reliability, availability, and maintainability) performance requirements and funding;
3. Emerging life-cycle program management best practices, including program support manager key leadership position and benchmarking of services, industry, and allied initiatives;
4. Contracting approaches to grow implementation of performance based logistics strategies; and
5. Enhanced Department of Defense (DoD) life-cycle workforce training, including new Defense Acquisition University courses focusing on business acumen and senior seminar for product support managers.

After highlighting current law and DoD policy related to each topic, examples of how lower aircraft sustainment costs have been achieved were summarized and considerations to institutionalize low-sustainment aircraft throughout the military service were proposed to workshop participants.

Speaker: James Yankel, Technical Director, Directorate of Logistics, Air Force Materiel Command

Presentation Title: Aging Aircraft Maintenance

The U.S. Air Force is going through a period of reduced recapitalization and increasing sustainment requirements as current fleets have lives extended 10 to 30 years into the future to maintain the current force structure. The efforts required to sustain these fleets is increasing both in material solution efforts, as failure modes beyond those identified in design begin to become more prevalent, and the resultant costs. Initiatives underway at Air Force Materiel Command (AFMC) are aggressively looking at sustainment of aging aircraft execution and issues. A discussion will be presented addressing the AFMC initiatives addressing organizational structure for sustainment, processes for sustainment as an enterprise, and technology development and insertion efforts for sustainment.

Speaker: Joann Berrett, Director, Aerospace Sustainment Directorate, Air Force Sustainment Center

Presentation Title: Driving to Cost-Effective Readiness

The Air Force Sustainment Center (AFSC) recognizes the challenges the U.S. Air Force continues to face to include aging aircraft fleets, the need to modernize weapon systems, rising weapon systems support costs, and fiscal constraints. We must reduce the cost of executing our mission. The cost of readiness will determine the size of our force, and the size of our force will determine our ability to fight and win the next war. AFSC is addressing the cost of executing its mission by focusing on cost-effective readiness through integrating efforts of organizations involved in sustainment activities. Recent success stories shared include reduction of flow days (or work-in-progress) for the KC-135 Stratotanker (the Air Force's primary in-flight refueling asset). This reduction in flow days resulted in the Oklahoma Air Logistics Center earning the 2011 Robert T. Mason Depot Excellence Award (first-ever Air Force winner). Another success story spotlighted a reduction in the number of C-130 Hercules "mission incapable" aircraft and improved due-date performance, another Robert T. Mason Depot Excellence Award Winner, but this time in 2012 (second Air Force winner in 2 years). Other success stories included improvements to the periodic depot maintenance for aircraft landing gear, concurrent E-3 Block 40/45 Modification installation (upgrade of electronics system on Airborne Warning and Control Systems), and propulsion alternate sourcing of parts. These efforts to date have provided seven additional KC-135s and 17 C-130s back to the field; reduced landing gear (Mission Incapable) MICAP hours by 91 percent; saved 8 months of depot possessed time for E-3s; and a cost avoidance of $65.4 million on propulsion parts.

Speaker: Mike Jennings, Deputy Director of Logistics (Acting), Air Force Life Cycle Management Center

Presentation Title: Product Support Responsibilities and Cost Reduction Initiatives

As the Air Force Life Cycle Management Center (AFLCMC) has evolved from planning efforts to standup, several initiatives have been pursued to ensure an emphasis on product support and the enterprise-wide role that now exists with the AFLCMC commander. As operations and support costs, including weapon system support costs, have continued to outpace inflation growth (FY1996-FY2011), AFLCMC now has an opportunity to execute an integrated, enterprise-wide product support strategy. Recommendations from the Life Cycle Management Working Group (LCM WG) and AFLCMC objective efforts can ensure enterprise visibility for the AFLCMC commander to exercise an influential role in product support activities across AFLCMC, as well as integrating product support management with the product support integrators and product support providers. AFLCMC has begun institutionalizing development of product support human capital, developmental planning, and logistics/health assessment recommendations from the LCM WG, as the AFLCMC commander has specific responsibilities in these areas. Other recommendations from the LCM WG will require a strengthening of AFLCMC commander roles/responsibilities. As initiatives progress, AFLCMC has the potential to ensure program office decisions are in-line with the Air Force enterprise product support strategy.

Speaker: Maj Mark Blumke, Deputy Chief, Mx Systems and Integration Branch, Directorate of Logistics, Air Mobility Command

Presentation Title: Air Mobility Command Initiatives to Reduce Maintenance and Sustainment Cost Drivers

No abstract submitted.

Speaker: SMSgt Kevin Mead, Air Force Element Vehicle and Equipment Management Support Office

Presentation Title: AFELM Vehicle and Equipment Management Support Office (VEMSO) Initiatives to Reduce Sustainment Costs

The Air Force is the fourth largest fleet within the federal government and supports more than 300 locations through 16 different regional headquarters. This results in significant duplication of effort and resources to meet the various missions. Knowing we cannot continue to operate this way in a fiscally challenging environment, Headquarters U.S. Air Force directed action to centralize management of the Air Force's vehicle fleet. The initiative is referred to as Installation Support Centralization (ISC). The ISC initiative consolidates enterprise vehicle fleet management and sustainment processes in support of logistics readiness operations, via Direct Liaison Authority (DIRLAUTH), with base level units, MAJCOM, and HAF staff. Consolidated activities are to be executed by AFELM VEMSO in the most efficient manner through continuous and deliberate reengineering of processes while enhancing global management and situational awareness of the Air Force's $7 billion vehicle fleet. Centralization has allowed AFELM VEMSO to implement several initiatives to reduce sustainment costs, including fleet validation/rightsizing and budget forecasting from an enterprise perspective. VEMSO is also leveraging technology to reduce costs with the implementation of the Automotive Information Management (AIM-2) system to collect vehicle data and automation of 10 fleet management processes to facilitate data integrity and reduce man-hour strains.

Speaker: Lt Col Brian Godfrey, Chief, Airborne Branch (A4CA), HQ Air Combat Command

Presentation Title: Air Combat Command Sustainment Challenges

Corrosion/structural cracks and wiring faults are factors driving sustainment costs in Air Combat Command (ACC). These factors are made worse by decreased manning, increased ops tempo, and aging fleets. Low observable (LO) maintenance in our fifth-generation fighter fleet continues to be an NM driver as well. ACC sees a potential for research into corrosion prevention, detection, treatment, and LO restoration to reduce sustainment costs. In addition, the ability to troubleshoot wiring and intermittent line replaceable unit faults with a test unit common across multiple airframes with more accuracy could greatly reduce sustainment costs. Finally, ACC would like to leverage state-of-the-art information technology tools, such as electronic tablets with mobile apps, to allow maintainers to reference tech data, conduct remote troubleshooting, order parts, close out work orders, etc., from the aircraft.

Speaker: BG Edward Dorman III, Director for Logistics Operations, Readiness, Force Integration and Strategy, Office of the Deputy Chief of Staff, G-4

Presentation Title: Informed Sustainment

The Army is developing “Lean” approaches to power and sustain its operations in the face of global, dynamic threats, while streamlining the force to meet resource constraints. Two examples, energy-informed operations and condition-based maintenance, tie investments and priorities to operational significance and risk. Energy enables all operational capabilities, but delivery incurs casualties and cost—about $2 billion per year in Southwest Asia. The Secretary of the Army has endorsed a new initiative to establish an “energy-informed” culture, which admonishes the total Army to behave in ways that maximize the net operational benefit from energy. This requires a combination of information, education, technologies, and processes to inform decisions and enable behaviors. Condition-based maintenance invokes a similar mission-informed decision process to focus reset efforts in order to manage risk and maintain a ready posture in the wake a decade of high operational tempo. Each of these initiatives illustrates a maturing Army capability to focus resources and priorities based upon mission demands.

Speaker: Joe Guenther, Vice President and General Manager, Evandale Turbofan and Turbojet Engines, General Electric Aviation

Presentation Title: GE Initiatives to Reduce Sustainment Costs

In 2011, the global fleet of military and commercial aircraft was powered by more than 50,000 engines provided by GE and its partners. GE Aviation is under a variety of service contracts to provide sustainment for, more than 11,000 of those commercial and military engines. Factors driving GE Aviation sustainment costs and how those factors change over time will be discussed. Examples of successful management of commercial and military engine sustainment costs will be examined, and emerging technologies that have demonstrated reduced sustainment costs will be presented. In closing, recommendations to take advantage of emerging capabilities will be provided.

Speaker: Raymond Valeika, Retired Senior Vice President for Technical Operations, Delta Airlines

Presentation Title: Sustainment: Managing the Consequences of Failure with Transparent Information

Sustainment or the maintenance of aircraft is a very complex business. The multiplicity of variables often drives actions and polices in a variety of directions. This then increases cost and often does not add to safety and availability of aircraft for the intended missions. This discussion deals with two fundamental issues in effective sustainment programs: understanding the consequence of failure and then assuring that proper information is available not only to understand the consequence of failure, but also to analyze life-cycle activities to determine their effectiveness. Consequence of failure determines the maintenance requirements. The analysis behind that is critical to ensure that both safety and economics are considered. Information is then the key for assuring the ongoing maintenance provides the necessary results. The free flow of information is critical in measuring and establishing goals and accountability. This paper discusses both the technical factors and organizational impacts of ongoing maintenance requirements and then gives some examples of programs that worked.

Speaker: Mike Buongiorno, Director, Military Engine Aftermarket Business Development, Pratt and Whitney (P&W)

Presentation Title: P&W Life Cycle Cost Management

With the continued emphasis on tight defense budgets both within the United States and our global allies, P&W remains aligned with our customers though our Integrated Program Deployment (IPD) strategy. Through IPD, P&W focuses on reducing the life-cycle cost of the propulsion system from product development, through production and into sustainment. P&W has demonstrated success in design for reliability/maintainability, production cost target achievement, and integrated sustainment solutions that not only reduce depot maintenance cost but also focus on reducing maintenance through increased time on wing, optimized operations and sustainment integration with original equipment manufacturer knowledge. P&W leverages lessons learned in legacy programs to drive continuous improvement into new products as well as flows new technology back into mature platforms to enhance their durability and reduce operating cost. P&W remains engaged with the services through the Component Improvement Program and other government and company-funded initiatives to reduce the cost of propulsion sustainment.

Speaker: VADM Walter Massenburg (USN, Ret.), Senior Director, Mission Assurance Business Education, Raytheon Company

Presentation Title: Enterprise, Why Now?: Naval Aviation Enterprise Model

In 1999, naval aviation was in crisis. As leaders of naval aviation in the 1990s prioritized building the future force structure to replace an aging aircraft fleet, the existing fleet continued to age, and the budget to preserve and manage the aging fleet was continually cut. Naval aviation faced the unprecedented crisis of having a force not ready to fight, while losing a generation of leadership. The “stovepipes” of operations, maintenance, and supply that contributed to current readiness retrenched and sought to optimize their activities at the expense of others. If not addressed, this “downward death spiral” would have resulted in a greatly reduced force structure, and warfighting capability would have been compromised. Across the years 1999-2007, naval aviation created a different business model which valued cost wise readiness and developed the concept of single process ownership and the single fleet driven metric to establish a horizontal behavior model that valued aviation units ready for tasking at reduced cost—today, tomorrow, and in the future. They adopted continuous process improvement (AIRSpeed), public private partnerships, performance based logistics, and other tools to enable the transformation. Today, the cost of naval aviation current readiness is predictable, billions of dollars remain in the Future Years Defense Program to recapitalize the force, and the level of readiness (availability) that is required is understood, achieved, and maintained. The Naval Aviation Enterprise operates as a true enterprise where readiness at reduced cost is everyone’s responsibility. Today, the Air Force is experiencing the same crisis that naval aviation experienced in the late 1990S—aging aircraft fleets, austere budgets, and “stovepipes” that drive cost. This naval aviation enterprise concept is applicable in any government organization; but now, as service budgets face severe pressures, the Air Force could use this current crisis to adopt an enterprise model and change from a “business of consumption of resources” to one that values a “business of conservation of resources.”